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PRELIMINARY DISPLAY LIMITS AND CREW MONITORING CONSIDERATIONS FOR TLI, LOI, AND TEI

By Charles T. Hyle
Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

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PRELIMINARY DISPLAY LIMITS AND CREW MONITORING CONSIDERATIONS FOR TLI, LOI, AND TEI

By Charles T. Hyle

1.0 SUMMARY

This paper suggests spacecraft display limits which will require crew action if exceeded during either of the three major maneuvers of the lunar mission - translunar injection (TLI), lunar orbit insertion (LOI) and transearth injection (TEI). In general, the limits consist of a total attitude deviation of 15° which will require engine shutdown and an attitude rate of 10 deg/sec which will require shutdown or manual takeover. This paper also assimilates information pertinent to the monitoring of these maneuvers.

2.0 INTRODUCTION

Because each of the three major burns - TLI, LOI, and TEI - required on the lunar mission will occur out of sight of ground tracking, the crew must use available displays onboard the command module to evaluate the maneuver. The major considerations for evaluating the progress of a maneuver are crew safety and mission success. Limits for the values displayed onboard must therefore be selected to insure crew safety and maximize mission success. Determining these limits and describing associated monitoring considerations are the primary objectives of this paper.

In addition, the paper has the following secondary objectives.

1. To help complete a set of lunar mission abort procedures currently being defined in the Mission Planning and Analysis Division (MPAD).

2. To provide realistic considerations for alternate mission and abort studies.

3. To point out related areas requiring further study.

The following displays may be used by the crew for monitoring the TLI burn.

1. Engine status light (S-IVB)

2. Launch vehicle (LV) rate light (referenced to the Instrument Unit - IU)

3. LV guidance light (referenced to the IU)

4. S-IVB tank pressures (referenced to the IU)

5. ΔV counter (X-axis accelerometer)

6. Computer - The DSKY quantities are read out from the command module computer (CMC).

7. Clock

8. IMU FDAI - The Inertial Measurement Unit (IMU) is the reference frame and the output is displayed on the Flight Directors Attitude Indicator (FDAI).

9. BMAG FDAI - Body Mounted Attitude Gyros (BMAG's) display attitude information on a second FDAI

The displays listed below may be used by the crew for monitoring both the LOI and the TEI burns.

1. IMU FDAI

2. CMC - DSKY

3. BMAG FDAI

4. ΔV Counter

5. Clock

6. Service propulsion system (SPS) tank pressures

7. SPS engine attitude indicator (engine gimball indicators - pitch and yaw)

From current procedures in MPAD, it will be assumed that system problems other than those affecting the maneuver will not be sufficient cause to terminate thrust. In other words, abort considerations require completion of the maneuver (either TLI, LOI, or TEI) if possible.

Since limits for S-IVB tank pressures are currently being established through the Crew Safety Panel and SPS tank pressure limits is a contractor responsibility, this paper will be concerned with the remaining displays. All remaining displays depend on the onboard reference systems.

The problem has now been reduced to an analysis of the trajectory and vehicle attitude to determine display limits beyond which crew safety or mission success would be jeopardized. Since spacecraft (SC) attitude information is displayed on the FDAI, the following information on the FDAI displays is included from reference 1. There are two FDAI's in the command module, each of which can display vehicle attitude, attitude rates, and attitude errors. The two sources available for driving these displays are the CMC and the gyro-display coupler (GDC). Either FDAI's can be driven by the CMC or the GDC, or the CMC can drive one FDAI while the GDC drives the other. If the CMC is driving an FDAI, spacecraft attitude and attitude rates are displayed with respect to the IMU. Attitude error, of course, requires the CMC to be performing a steering computation. If the GDC is driving an FDAI, spacecraft attitude is measured with respect to the BMAG's. Attitude rates are obtained from rate gyros. An attitude error which is the difference in the crew-input angle on the attitude set dials and the instantaneous spacecraft attitude can be displayed. The FDAI's have variable scaling which is controlled by a switch. The following scales for pitch, yaw, and roll are available on the block II spacecraft.

Attitude error, deg	Attitude rate, deg/sec
5	1
5	5
50/15	50/10

The total attitude scale ranges from 0° to 360° in pitch and yaw and includes the gimbal lock region. A chart showing an FDAI display is shown in figure 1.

Because abort techniques to return the crew safely to earth and alternate mission plans are currently defined relative to a nominal trajectory, attitude information and trajectory limits should be constrained to prevent large deviations from the nominal trajectory.

In general, it is expected that large rates that could occur from failures such as an engine hardover will be detected and reacted to very quickly. Failures of this kind will not cause significant trajectory deviations, but could break the vehicle. On the other hand, a drifting platform could produce slow deviations that were not readily detectable. Continuation of the maneuver with such a failure could produce significant trajectory deviation and possibly an impact. The display limits must, therefore, protect against both fast and slow rate deviations.

An important ground rule may now be stated. The only action required by the crew during either of the 3 burns will be due to attitude rate buildup or attitude deviations and as a result of this action, the trajectory will be kept close to the expected.

Action required will depend upon the maneuver being made and the ability of the crew to determine the failure source. During TLI, the action required is S-IVB shutdown; LOI and TEI require manual completion of the maneuver, if possible.

The following sections describe the factors influencing the selection of onboard display limits.

3.0 TRANSLUNAR INJECTION

3.1 General Monitoring

3.1.1 Error source identification.- The nominal TLI burn will be controlled with attitude reference information provided by the IU. This fact makes monitoring TLI much easier than monitoring the remaining burns because there are three independent systems. That is, the erroneous system may be determined because the other two are producing expected outputs. For example, a slowly drifting IMU would not produce the expected DSKY output of V_g if a good IU is being used to control the burn. Also, the BMAG FDAI and the ΔV counter would indicate a nominal burn. A slow drift in the IU would not be caught by the LVDC reasonableness test, but would, however, be detected since the DSKY values and FDAI total attitudes would not be nominal. A slow drift on the BMAG's would be detected because the DSKY output would appear normal.

Verification of a fast rate indication would be simpler with the addition of physiological and out-the-window cues.

3.1.2 Initial alignment.- In order to have the highly desirable characteristic of 0, 0, 0 on the FDAI's at TLI ignition, the IMU will have to be aligned in parking orbit - as will the BMAG's - so that they are along the LV body axis in the initial thrust direction at ignition. Even though the LV reference frame (IU) will not have the same alignment, the CMC can compute the attitude error, which should be almost the same as that of the LVDC. This will also be subject to differences due to spacecraft and LV steering.

3.1.3 DSKY parameters.- It is noted that the CMC operating under GSOP program 15 can be used to monitor or control the TLI burn. In either case, the DSKY quantities appearing in the three registers are the time remaining to cutoff (t_{go}), velocity to be gained (V_{go}), and the total velocity increment sensed, including ullage (ΔV_m).

Orbital parameters are also available for display during the burn by using routine 30. These quantities are apogee altitude (h_a), perigee altitude (h_p), and time to perigee (t_p). The crew may call routine 30 anytime during the burn and return to the thrust parameters at will.

The LVDC or the CMC - whichever is in control - will issue the cutoff signal when the target conditions have been achieved. The command module ΔV meter can provide a backup for S-IVB shutdown. For a second revolution February 1, 1968, launch date, the value of ΔV read from the meter at nominal shutdown will be about 10 509 fps.

3.2 Slow Rate Considerations

3.2.1 Effects of gyro drifts.- Because TLI begins in a 100-n. mi. circular orbit and is a guided burn, which has various feedback loops guarding against "unreasonable" - fast rate - maneuvers, the slow drift trajectories are the ones which might cause an atmospheric entry. Current studies have shown that a gyro drift rate of approximately -0.2 deg/sec in the pitch plane used through the TLI burn would be the smallest value which would produce an imminent entry situation. (See fig. 4b). The IMU FDAI display of attitude error - instantaneous difference in commanded attitude and actual attitude, calculated using cross-product steering - would produce an indication of a drift rate in the IU of this magnitude, late in the burn. Also, the crew would notice, late in the burn, that the total attitude had diverged.

This suggests the TLI slow drift be terminated on a total attitude difference from the expected attitude history. It is noted that -0.2 deg/sec would induce a total pitch attitude difference from the nominal at TLI cutoff of about 65°; however, since there is no way to correct the drift, a much lower value should be used for the cutoff criteria.

3.2.2 Alternate mission constraints.- As stated earlier, it is desired to prevent large deviations from the nominal trajectory in order to conform to abort and alternate mission plans. This means that the case discussed in the last paragraph should be terminated long before an imminent entry situation could develop.

From references 2 and 3 approximately 85 per cent of the nominal TLI burn would be required to produce an orbit suitable for currently planned alternate missions involving the moon. That is, approximately 300 seconds of the TLI burn is required to obtain an apogee of 30 000 n. mi. from which some hybrid alternate mission might possibly be flown. Since alternate missions with apogees less than 30 000 n. mi. would probably be a high-earth-ellipse simulation of lunar mission timelines, a TLI which will not produce a 30 000-n. mi. apogee may as well be terminated. The largest drift that will still provide a 30 000-n. mi. apogee is about $\pm$ 1 deg/sec. This means for a 330-second burn a total attitude deviation of 33° would result. Attitude deviations larger than this could not produce the desired apogee. Therefore, this value of 33° would be the upper limit. Drift rates faster than 0.1 deg/sec would then require TLI shutdown and those less than 0.1 deg/sec could possibly produce the hybrid lunar alternate mission. Since drift rates of this magnitude are several orders of magnitude larger than $3\text{-}\sigma$ drift rates and, therefore, represent failed hardware, there is little reason for attaching special significance to the number 0.1 deg/sec. Therefore, for conservatism, if 0.05 deg/sec is used, a limiting value of total attitude deviation at the end of TLI of about 16° results.

Changing the acceptable drift rate from 0.1 deg/sec to 0.05 deg/sec will exclude a negligible number of possible lunar hybrid alternates.

In summary, a total 15° attitude deviation between the two FDAI displays should be used as TLI termination criteria regardless of the rate that caused it. Total attitude deviation should not be confused with the attitude error.

It is noted that a platform misalignment in the pitch plane large enough to cause the imminent entry case would have to be about -20° to -25°.

3.2.3 Fuel budget.- Although a small TLI drift rate during TLI exists which the nominally budgeted midcourse could readily correct, it would naturally be much smaller than the -0.05 deg/sec rate previously used to establish the attitude deviation limit. The acceptance of the hybrid lunar missions and alternates currently being studied will exert a strong influence on the allotted ΔV available for correcting for slow deviation trajectories (i.e. the argument of perigee). In other words, some of the hybrid mission profiles may be able to correct for larger rate deviations than 0.05 deg/sec and would, thereby, change the suggested value of 15° total attitude deviation.

3.2.4 CSM control of TLI.- Another factor pertinent to this discussion would be the influence on the attitude deviation limit if the switchover decision were made to have the CM instead of the LV provide guidance during TLI. During this situation, the CMC, using the IMU and cross product steering would be controlling the burn.

Because making the switchover decision implies a LV platform failure of some kind, it is assumed that the LV rate or guidance light will be meaningless if lit during TLI. If the IMU began a slow drift, the total attitude display on the BMAG FDAI would read differently from the expected, and out-the-window views would probably be required to identify the error source. The S-IVB should then be shutoff when the BMAG FDAI indicated a total attitude difference of 15° from the nominal. On the other hand, if the BMAG's began to drift, the IMU FDAI would display expected output, and the window view would again be required to determine the error source. This burn should be continued.

3.3 Fast Rate Considerations

3.3.1 Commanded rates.- Selection of the attitude rate limit for TLI shutdown requires knowledge of the possible rates which could be introduced or result from normal occurrences. The S-IVB is limited to maximum controlled turning rates of 1.0 deg sec, even though commands may be higher. The CM, on the other hand can, under guidance and navigation (G&N) control, command 4.0 deg/sec rates. Under SCS rate command, 8.0 deg/sec is possible. It is also noted that the SPS would be used to overcome excessive rates built up by the S-IVB during a TLI which required an abort.

3.3.2 Suggested rate limit.- Although the angular rate which would break the spacecraft at the CSM interface is of the order of 70.0 deg/sec (ref. 4), there is no reason to expect LV recovery if a high rate developed. Therefore, to avoid crew discomfort, possible damping problems, and unnecessary spacecraft fuel usage, and for consistency with previously designated S-IVB rate limits (ref. 4 and 5), a rate limit of 10.0 deg/sec is suggested for TLI shutdown criteria.

3.4 Description of Figures

Typical histories of previously discussed quantities through the TLI burn of reference 3 are included for completeness. The injection takes place about 2 hours after lift-off in the 2nd revolution. Crew orientation with respect to the earth and parking orbit plane are depicted in figure 2. The DSKY quantities are shown in figure 3 through 4b for the nominal and drifting platform case. Vehicle attitude information is provided in figures 7 and 8. The parameters, inner gimbal angle (IGA), and middle gimbal angle (MGA) represent pitch and yaw with respect to the IMU. Pitch (P), on the other hand, is measured with respect to the local horizontal. If the spacecraft ORDEAL system which torques the FDAI at the spacecraft orbital rate is used and can be set for a 100-n. mi. circular orbit, the pitch parameter will be seen on the FDAI instead of the IGA. Adding the central angle traveled to the pitch history provides the vehicle pitch attitude (inertial) history as would be shown by the BMAG FDAI if a drifting IMU were controlling the maneuver (see fig. 8). Orbital parameters are shown in figures 5 and 6.

3.5 Summary Remarks

In conclusion, monitoring the TLI for attitude and rate deviations is at best a difficult task. For the most probable situations where the S-IVB is controlling the burn, if both FDAI's deviate the LV is malfunctioning and will require a shutdown on the specified limit. If only one FDAI deviates and the other appears nominal, the deviating FDAI is in error, and the burn should be completed. When the CMC is controlling TLI the problem is more difficult, and requires out-the-window cues to identify the failed system before making the shutdown decision.

It is noted that none of the items considered offers an absolute reason for selecting one value over another for TLI shutdown limits. However, they do suggest that an attitude rate of 10.0 deg/sec and a total attitude deviation of 15° would provide adequate S-IVB shutdown limits.

4.0 LUNAR ORBIT INJECTION

4.1 General Monitoring

4.1.1 Error source identification.- Many of the factors influencing error source identification and limiting selection for TLI also apply for LOI. The most significant difference is that, if one of the FDAI's available for crew monitoring indicates a slow deviation, there is apparently no method to determine which one is in error. Pilot observations of star patterns for attitude information is complicated both by the LM, which is now attached to the CSM nose, and by the fact that LOI is a curved burn. If the IMU is drifting, it will provide FDAI and DSKY displays which appear normal. Because the IMU is in control, the BMAG FDAI, on the other hand, will deviate in total attitude regardless of whether the IMU or the BMAG's is in error. Since there is no way to determine which system is at fault for an observed BMAG total attitude deviation, the only alternative would be to shut the SPS off.

4.1.2 DSKY parameters.- A brief description of the CMC programs to be used for LOI is included for completeness. Given the time of ignition, the target vectors, and the time from ignition until the target is achieved, the crew will use prethrust program 31 to verify the ground targeting by observing the computed values of apoapsis, periapsis, and delta velocity at ignition. After proper SC and platform orientation, the CMC, using program 40, will initiate the burn and display the following quantities:

TFI time from ignition which changes to T_{go}

T_{go} time required to complete the burn

V_{go} velocity to be gained

ΔV_m total velocity input - includes ullage.

After cutoff the components of any incremental velocity requirements remaining are displayed for nulling with the RCS. Routine 30 then displays orbital parameters, but may also be called up during the burn.

Although the CMC will normally terminate the burn, the ΔV counter, clock, and thrust-off switches will be used to prevent overburns.

4.1.3 Initial mistrim.- Another item influencing the LOI limit settings is the possible angular motion caused by a thrust vector misalignment and the control system requirements for the CSM/LM configuration. For a fully loaded SPS and a 1° thrust vector misalignment, an attitude deviation of from 8° to 10° may occur during the first 15 seconds of the maneuver (ref. 6). The crew will be expecting this deviation, and will not take corrective action.

4.2 Slow Rate Considerations

4.2.1 Effects of gyro drifts.- Since a drift rate in pitch of -0.05 deg/sec, or a misalignment of about 10°, through the LOI burn is about the smallest rate which causes lunar impact, it is suggested that this rate be used to establish a total attitude deviation beyond which the burn should be terminated. By not using the smallest rate, some conservatism is included.

For consistency with TLI, if a 15° total attitude deviation is again used as a limit, a LOI burn with an IMU drift of -0.05 deg/sec would be shutdown at 300 seconds. The resulting orbit would be stable, and have an apocynthion of 858 n. mi., a pericynthion of 62 n. mi., and a period of about 4.0 hours. For slower drift rates, the burn would be shutdown later, but with no impact problems; for faster rates the burn would be cut off sooner. Rates between -0.09 and -0.11 deg/sec might result in an unstable orbit. However, as soon as the spacecraft became visible from the earth, the crew would be informed which system was in error and whether to abort or complete LOI.

4.2.2 Possible manual procedures.- If the crew should happen to know that the IMU was drifting during the burn, it is suggested that they complete the burn manually to avoid an undesirable lunar orbit. Some of the techniques which seem feasible are as follows:

1. Assume the nominal inertial attitude at the takeover time and complete the burn.

2. Assume an optimum attitude - from 10° to 30° for pitched-down drifts - and complete the burn.

3. Do either of the first two for a minimum time to produce a stable orbit from which to abort.

In any case, the crew would take over at a total attitude deviation on the BMAG FDAI - possibly 10° to 15° - and complete the burn using the BMAG FDAI for reference. The switchover limit depends on the ensuing procedure and vice versa. Trajectory studies are currently under way to determine the takeover procedure which are safest for the crew and thereby identify the limit. Some studies have been documented in reference 7.

4.2.3 Manual mode setup.- Since the ground has much more information on the IMU status prior to SC occultation, it is highly unlikely that the system would fail during LOI without any previous indications. However, should it fail and the crew know the IMU was bad, the manual takeover mode with the SCS could be accomplished under the following conditions.

1. The IMU and BMAG's were aligned at LOI start.

2. The ΔV counter on the EMS had been set with the proper value - about 3200 fps - prior to LOI start.

3. The thrust vector control switch were in the acceleration command positions. (Rate command may not provide stability with the LM attached.)

4. At the limiting deviation of X° in total attitude, the pilot would switch control from the CMC to SCS by rotating the translation control switch clockwise.

5. The pilot would then hold a fixed inertial attitude until the ΔV counter shut off the SPS or until a minimum burn time. The engine can also be shut off with the ΔV thrust switches.

4.3 Fast Rate Considerations

4.3.1 Control.- The IMU FDAI is the key display for indicating high attitude rate. If the IMU FDAI displays a high attitude rate and the spacecraft is actually spinning, then control should be regained with the manual SCS mode and the BMAG's. If the IMU indicates a rate when the SC does not have one, then manual control must again be assumed because the IMU is faulty. Therefore, for observed high rates on the IMU during LOI, the pilot should take control, remove them, and continue the burn.

Probably the most likely cause of a high rate would be due to an engine actuator hardover. At the limiting rate the pilot would assume manual control, which also brings in the redundant actuator system. If control is regained, the pilot may then fly the attitude error needle - keeping attitude error zero - since the CMC is still operating correctly. On the other hand, he may return control to the digital auto pilot - CMC.

If the actuator itself has failed the engine must be cut off to avoid excessive rates. The RCS would then be used to remove the rates. Preliminary calculations show that two RCS quads could remove rates of 10 deg/sec without using budgeted RCS propellant. Since the CMC can command up to 4 deg/sec the rate limit should not be too close to possible commands. Therefore, a rate limit of 10 deg/sec is suggested as a preliminary value.

4.3.2 Other studies.- It is pointed out that the Guidance and Control Division is planning LOI simulations at NAA in the near future (ref. 8) and that only through man-in-the-loop simulations can realistic limits be set and procedures made. A detailed study is also under way in the Structures and Mechanics Division to insure the manual takeover procedures adopted do not result in breaking the LM off the CSM.

4.3.3 Description of figures.- The geometry of the LOI maneuver, DSKY and FDAI parameters, and orbital elements are shown in figures 9 through 15.

Note that the data used in these plots were obtained from a simulated CMC program which has just been deleted. The program substituted in its place accomplishes the same lunar orbit, but the parameters shown would appear slightly different. Comments and conclusions drawn in this section are not affected.

4.3.4 Summary remarks.- In summary, it appears that an attitude rate limit of 10 deg/sec may be used as a manual takeover cue during LOI. Depending on the failure, a manual mode - being studied - or CMC attitude error needles would be flown to LOI completion. If control cannot be regained, the engine should be shutdown, and the RCS should be used to obtain zero rates. For a drifting platform in which one FDAI indicates a total attitude deviation, the engine should be cut off on a deviation of 15° from the nominal. If the IMU is known to be drifting, a manual mode should be flown to LOI completion.

5.0 TRANSEARTH INJECTION

5.1 General - Monitoring

The TEI maneuver takes place on the far side of the moon in darkness, and is initiated from an 80-n. mi. circular orbit. The major differences between TEI and LOI which could effect monitoring and crew action limits are as follows:

1. The maneuver is posigrade and the LM has been jettisoned.

2. The burn is much shorter - 120 second - and is made at a nearly constant inertial attitude.

Probably the most significant thing these differences might provide is the capability to determine which reference system is in error for the slow-drift case. That is, the window view of the stars will be different from the expected if the SC is deviating due to an IMU drift.

5.2 Slow and Fast Rate Considerations

With the noted exceptions, comments made under the LOI section apply for the TEI burn. In brief, the limiting considerations follow.

1. Suppose the BMAG FDAI indicates a slow drift, and the IMU FDAI does not and the crew knows which indicator is wrong. If the BMAG's are wrong, the crew will ignore the drift; if the IMU is wrong, they will take over manually and complete the burn. The takeover limit and procedures are being studied presently.

2. If the crew is unable to determine which system is actually drifting, they should cut the engine off on a suggested total attitude deviation of 15° to avoid an impacting trajectory. That is, an IMU gyro drift toward the moon can result in an imminent SC impact. The 15° limit will provide a non-time-critical orbit from which the ground can track and advise the SC. The faulty system will be identified and an abort maneuver recommended.

3. In the event of fast SC drift rates, the crew should switch to manual control at a suggested 10 deg/sec. If the SC is controllable, they may either fly the attitude error needles, return control to the CMC, or fly some other manual technique. If the SC cannot be controlled, the engine should be shut down and the rates nulled in the RCS. It is noted that rate command is available without the LM.

The geometry of the maneuver, the DSKY quantities and orbital parameters are provided in figures 16 through 21.

6.0 CONCLUSIONS

Crew monitoring during TLI, LOI, and TEI has been briefly discussed and preliminary spacecraft display limits suggested. In addition to the above primary objectives, the paper is intended to help define a set of lunar mission abort procedures currently being formulated in MPAD. It also provides realistic considerations from which alternate missions and abort studies may be planned. Related areas requiring further study are pointed out.

A detailed summary of the suggested limits is presented in table I. In general, the limits consist of a total attitude deviation of 15° which will require engine shutdown and an attitude rate of 10 deg/sec which will require shutdown or manual takeover.

The total attitude limit was derived primarily by considering effects of a downward drifting platform - pitch plane - on the resulting TLI, LOI or TEI trajectory. The limit is, therefore, intended to prevent an imminent SC impact. For simplicity the limit is suggested for the other axes as well.

The fast rate limit was selected in a more arbitrary manner after due consideration to possible circumstances which could exist in a fast rate situation. It is emphasized that man-in-the-loop simulations to be conducted in the near future will determine the adequacy of the limit. It is also suggested that the 10 deg/sec limit be used for yaw and roll as well as pitch.

Although the magnitude of both the limits suggested may seem large, it is intended that they provide the maximum opportunity to complete the maneuver and to evaluate SC systems before requiring crew action. Several important studies and simulations are necessary before these limits are finalized; however, the values suggested in this paper may be useful for planning.

TABLE I. - SUGGESTED DISPLAY LIMITS

Display indication	Action required at display limit [a]	
	TLI	LOI and TEI
Total attitude deviation (Protects against slow gyro drifts)	Engine shutdown at 15°	If error source is not known, engine shutdown at 15°. If error source is known, .Manual completion if IMU is drifting. [b] .Automatically completed if BMAG's are drifting.
Spacecraft rate (Protects against engine hardovers, fast rates, etc.)	Engine shutdown at 10°/sec	Manual takeover at 10 deg/sec, If controllable - actuator works - complete burn. [c] If rate continues, engine shutdown and reduce rates with RCS.

[a]The limits are intended to apply about any axis.

[b]Limit and procedure are being defined.

[c]Fly attitude error needles, if valid, or return control to CMC. For IMU or CMC failure, fly manual procedure (being defined).

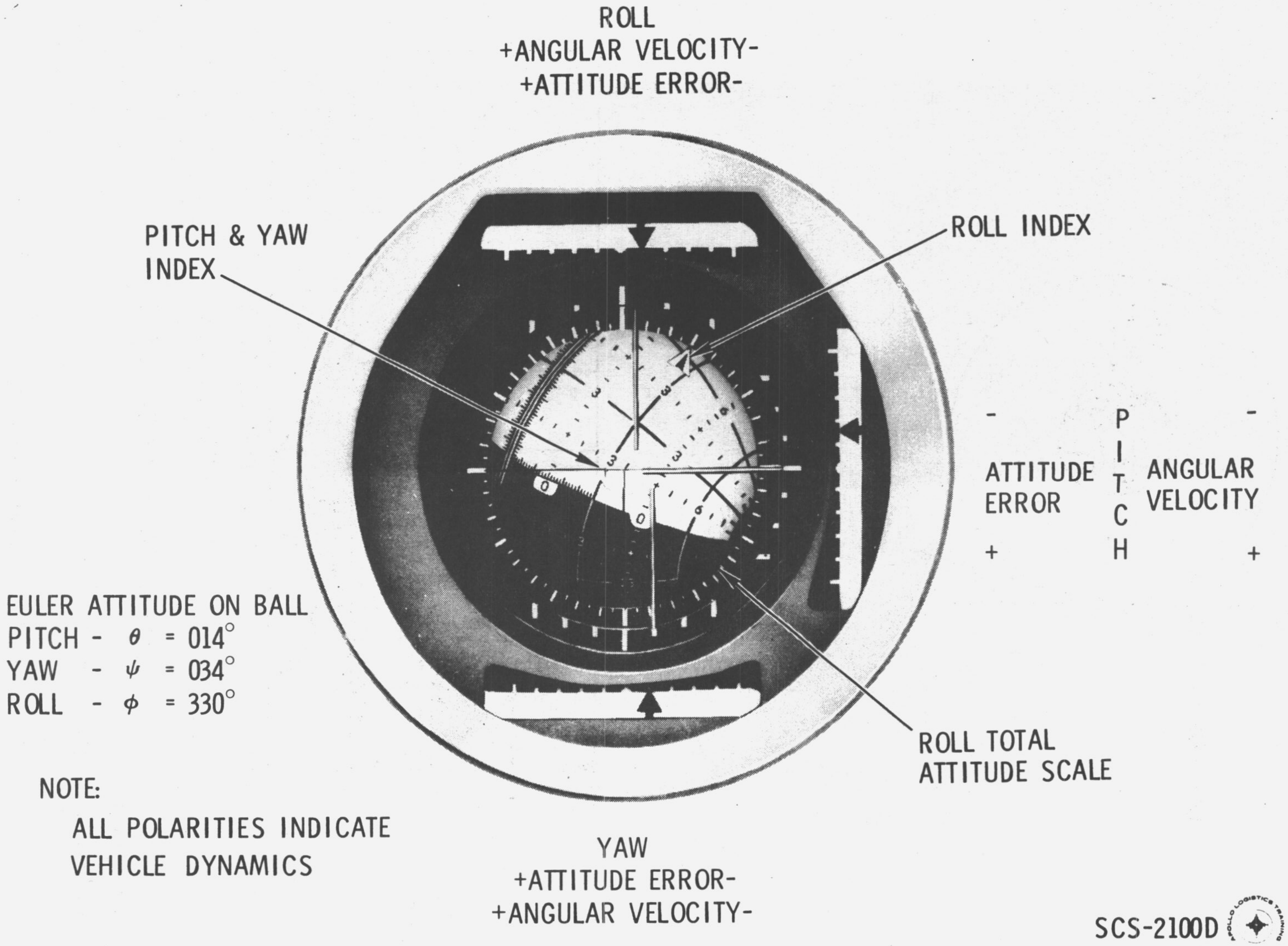
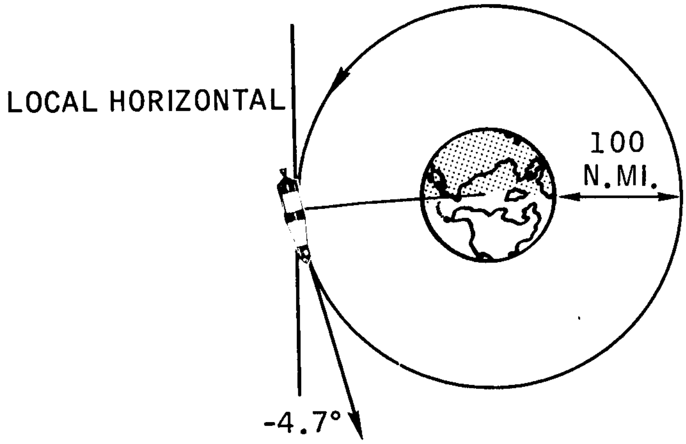
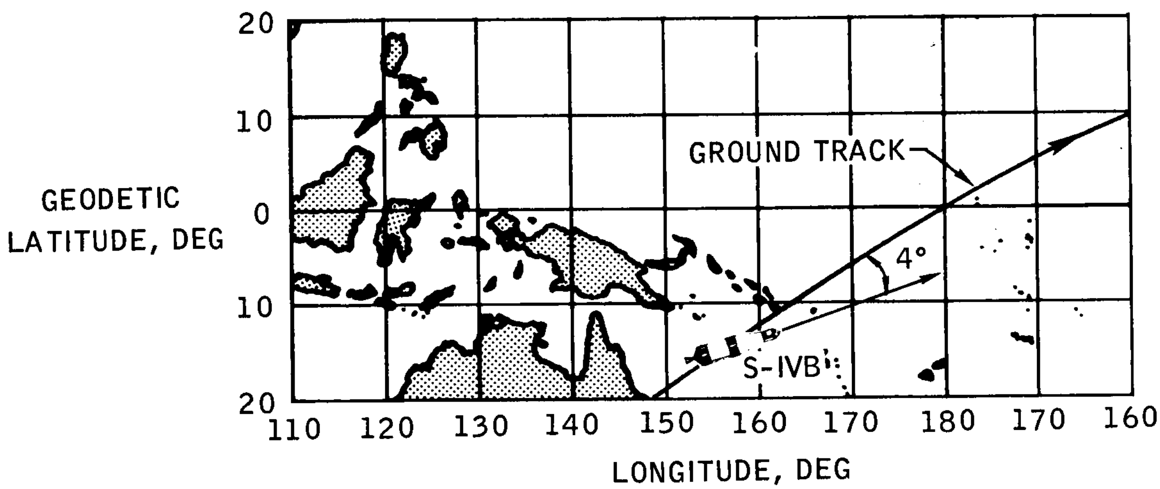


Figure 1.- Flight Director attitude indicator.



PITCH WITH RESPECT TO LOCAL HORIZONTAL



YAW, LOCAL HORIZONTAL SYSTEM

DATA REFERENCE:
MSC INTERNAL NOTE NO. 66-FM-70

Figure 2. -Launch vehicle attitude at TLI ignition.

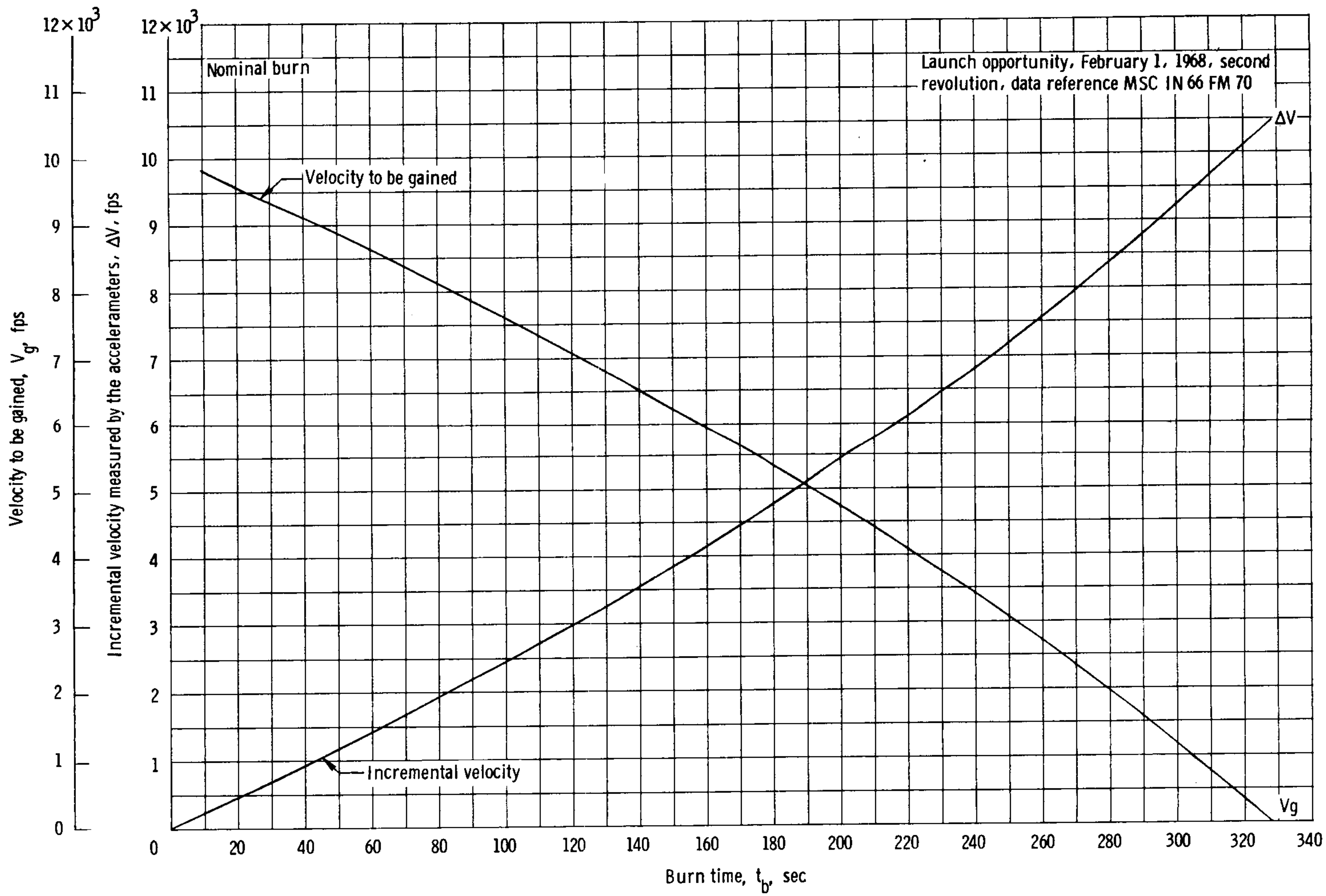
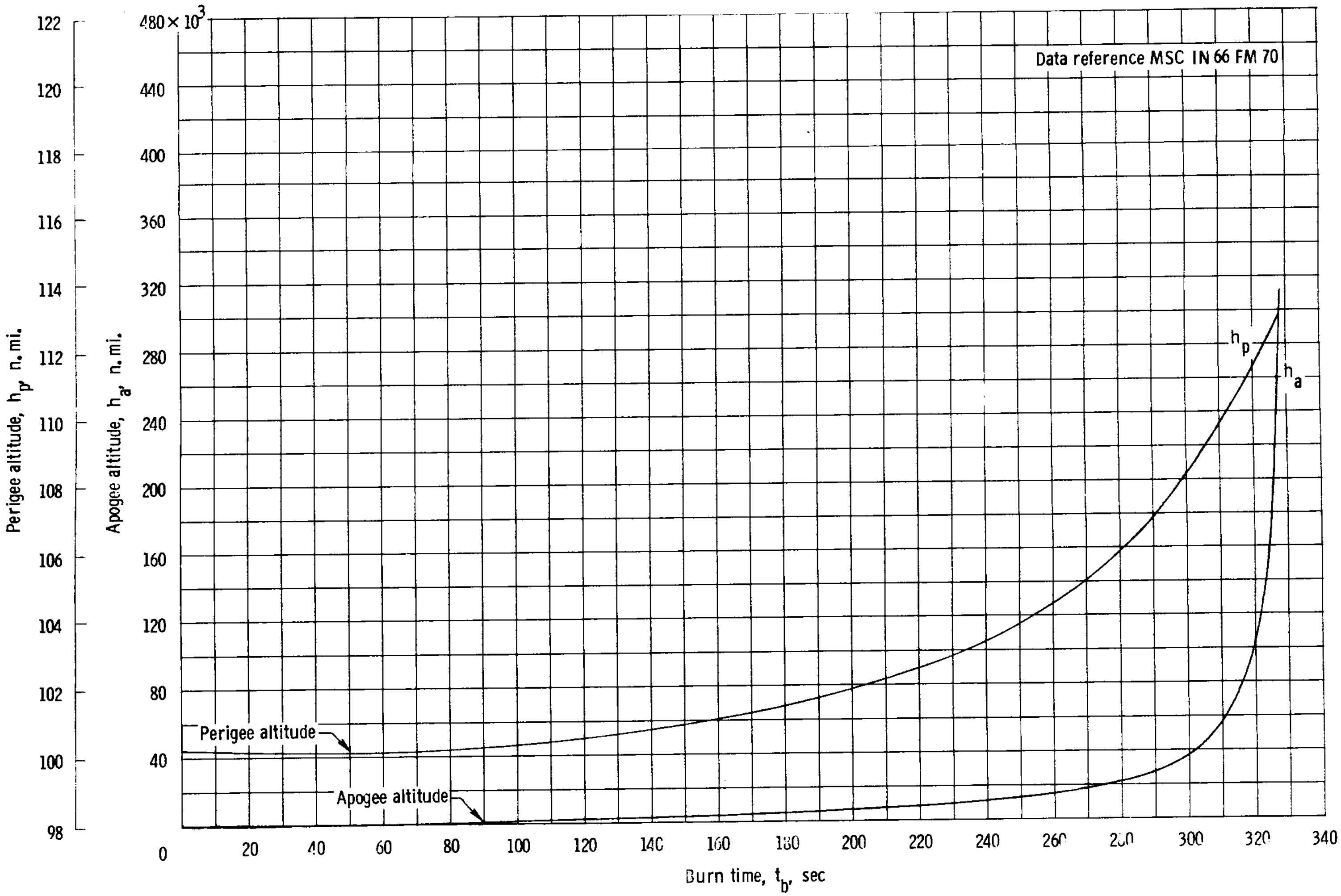
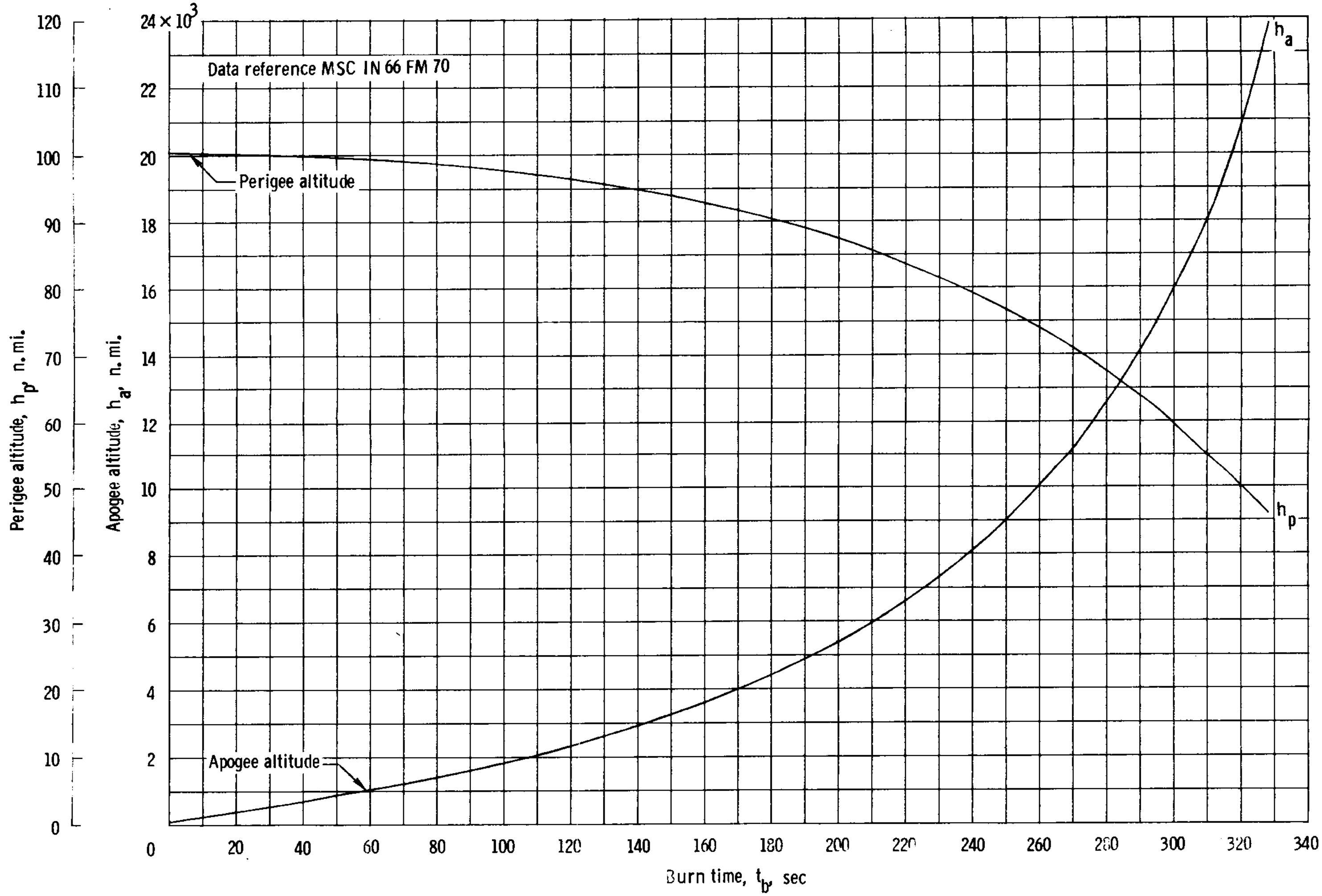


Figure 3. - DSKY parameters through the translunar injection burn.



(a) Nominal burn.

Figure 4. - Apogee altitude and perigee altitude through the translunar injection burn.



(b) Platform drift of -.2°/sec.

Figure 4. - Concluded.

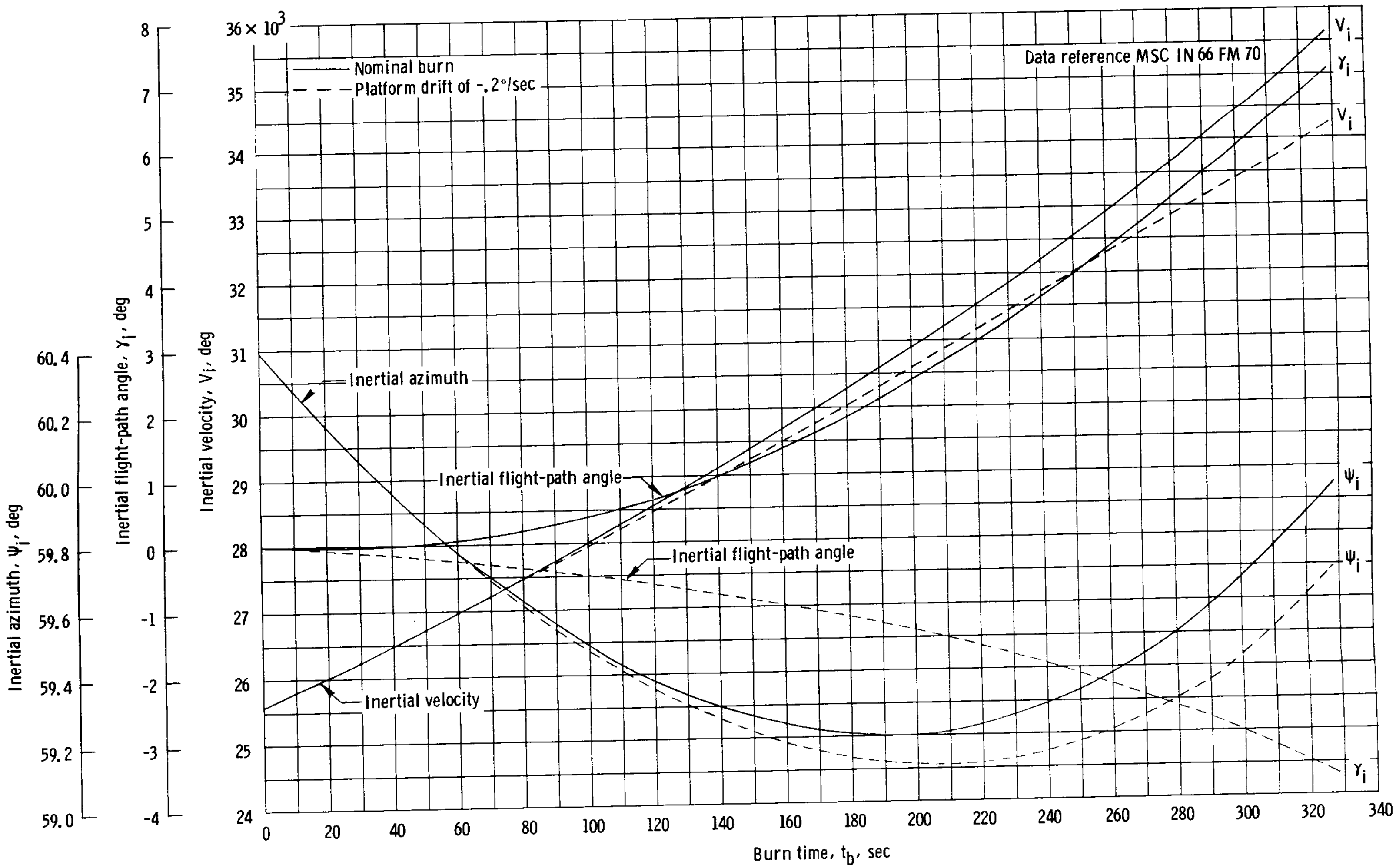


Figure 5. - Inertial velocity, inertial flight-path angle and inertial azimuth through the translunar injection burn.

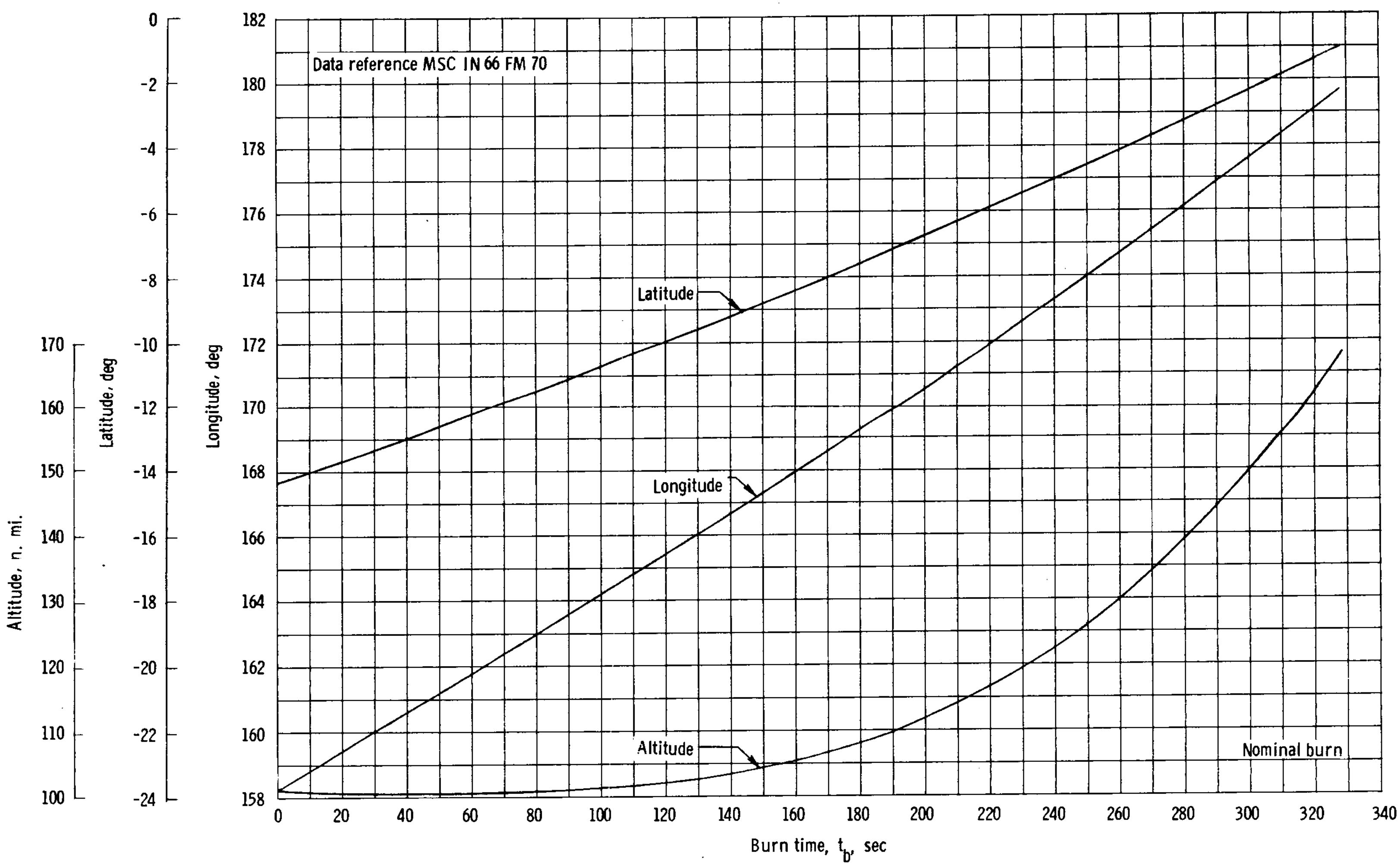


Figure 6. - Latitude, longitude and altitude through the translunar injection burn.

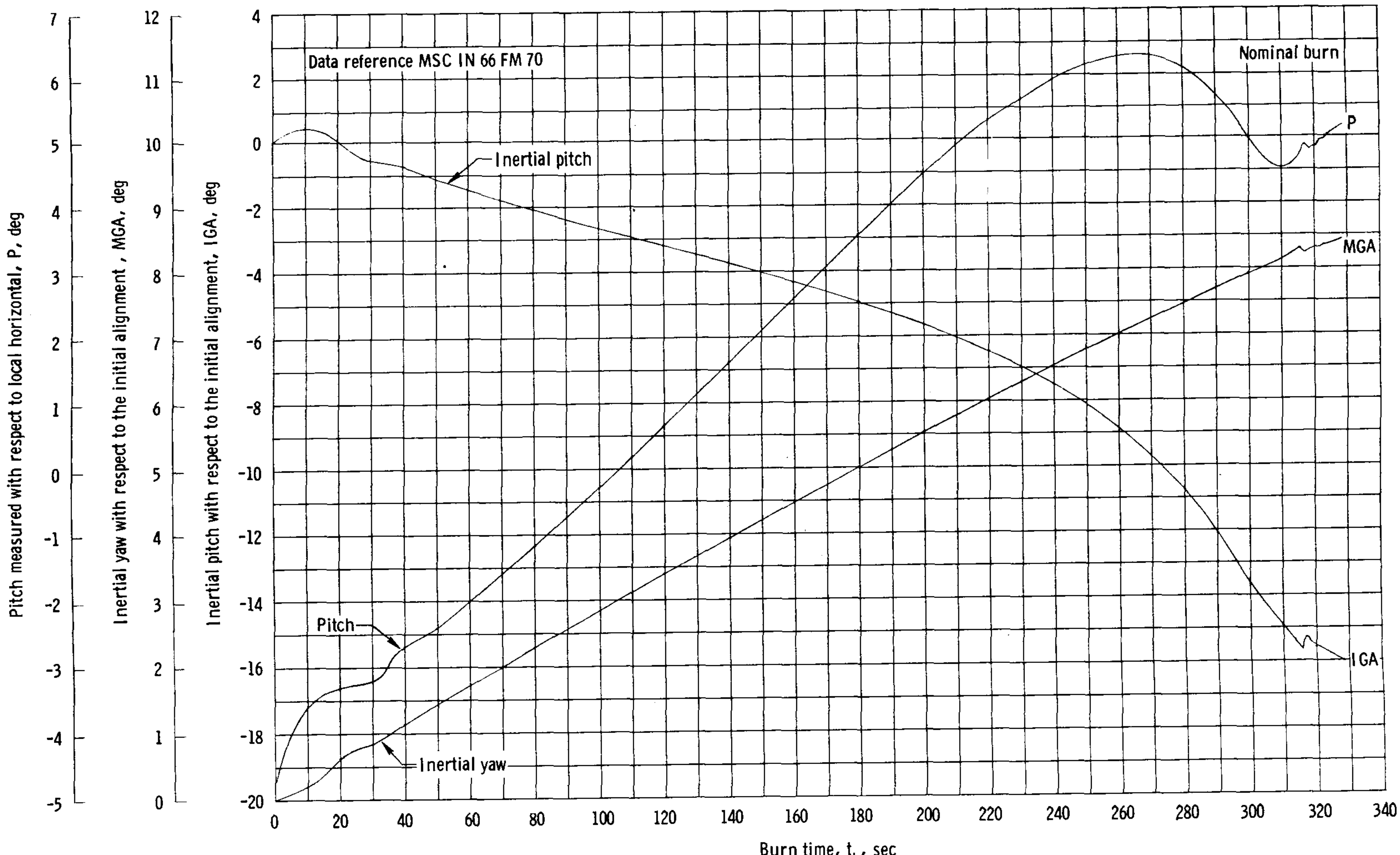


Figure 7.- Launch vehicle attitude through the translunar injection burn.

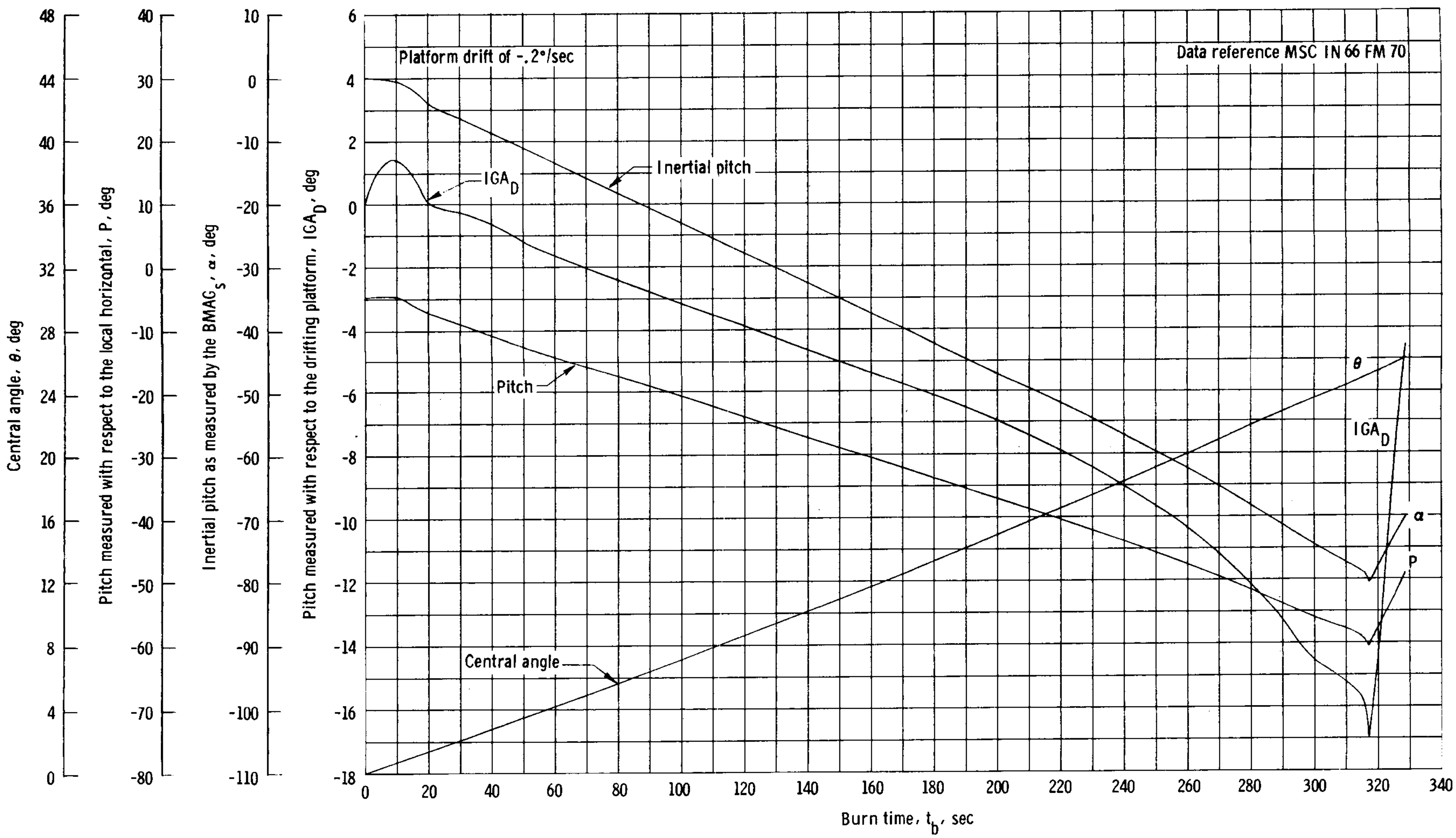
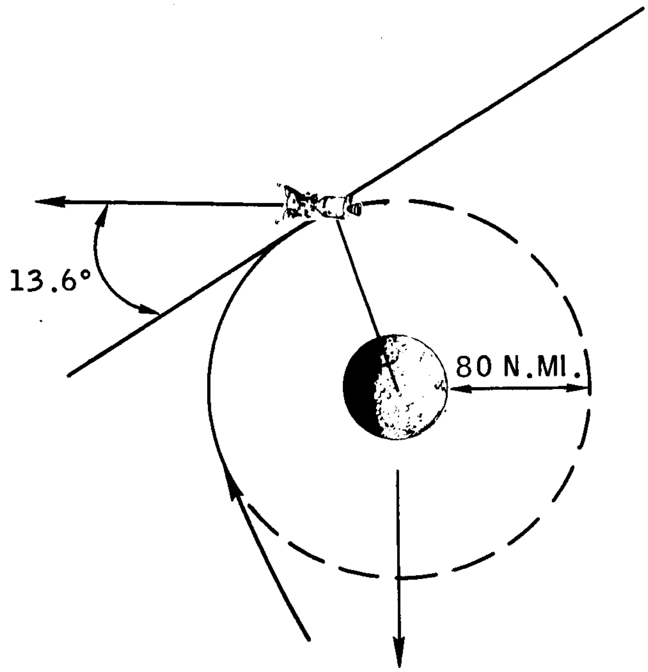
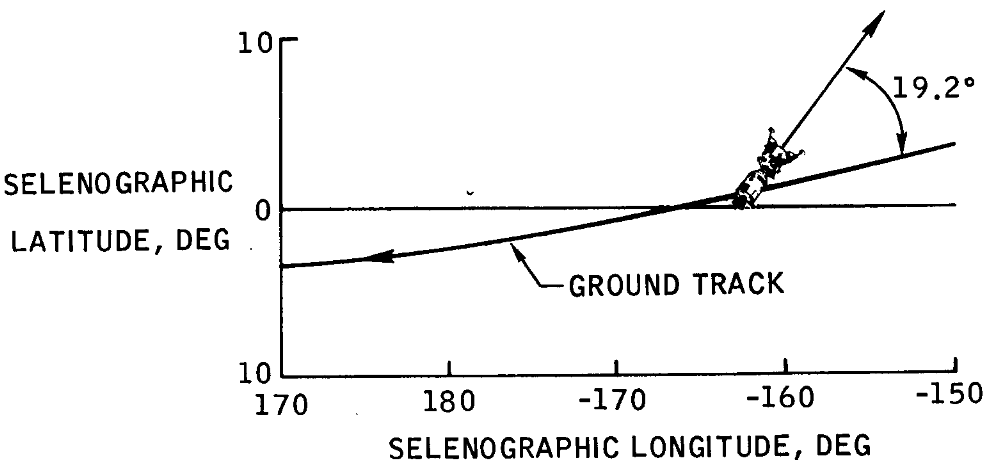


Figure 8. - Launch vehicle pitch attitude through the translunar injection burn as performed with a platform drift.



PITCH WITH RESPECT TO LOCAL HORIZONTAL



YAW, LOCAL HORIZONTAL SYSTEM

Figure 9.- Spacecraft attitude at lunar orbit injection.

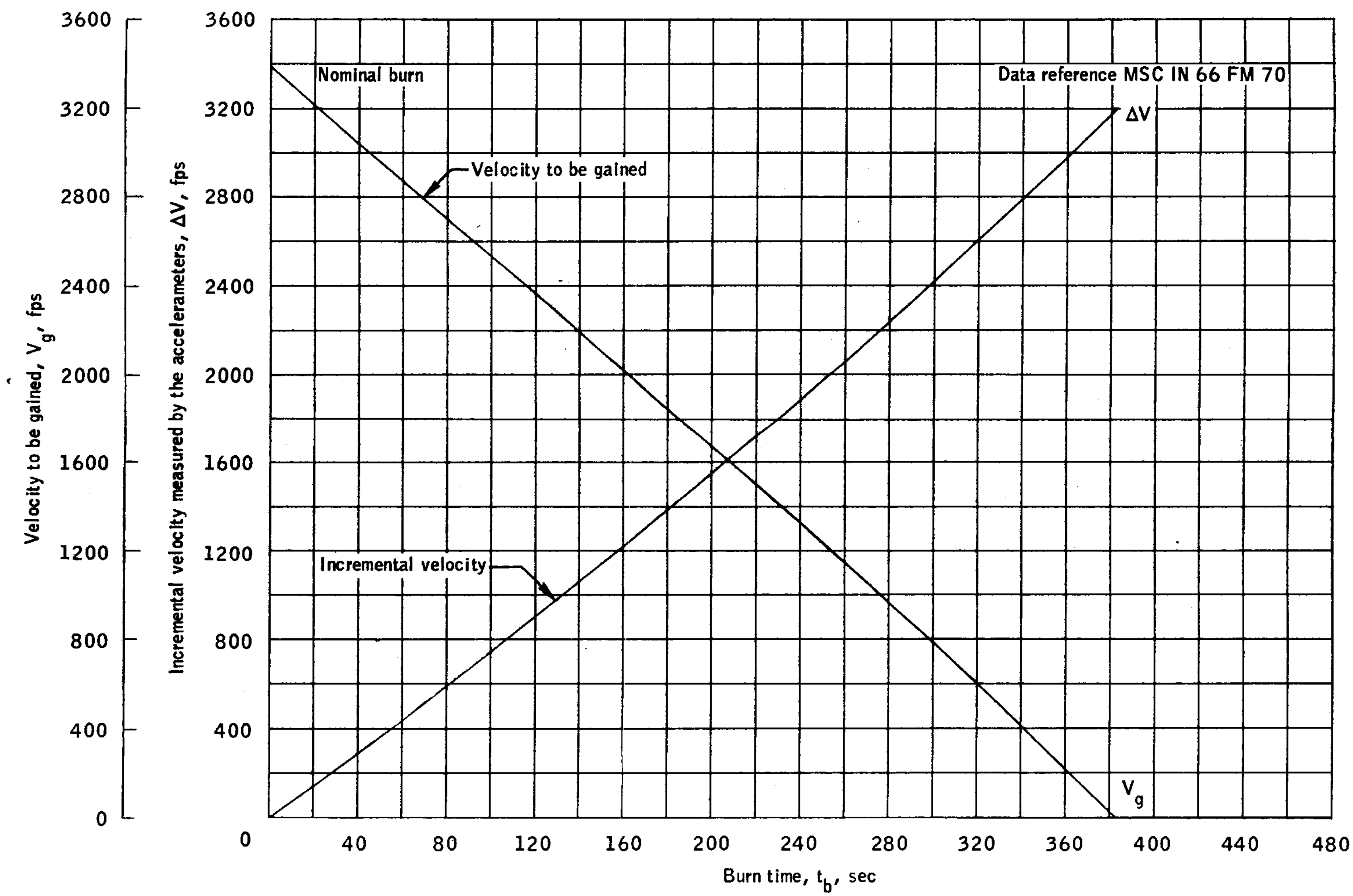
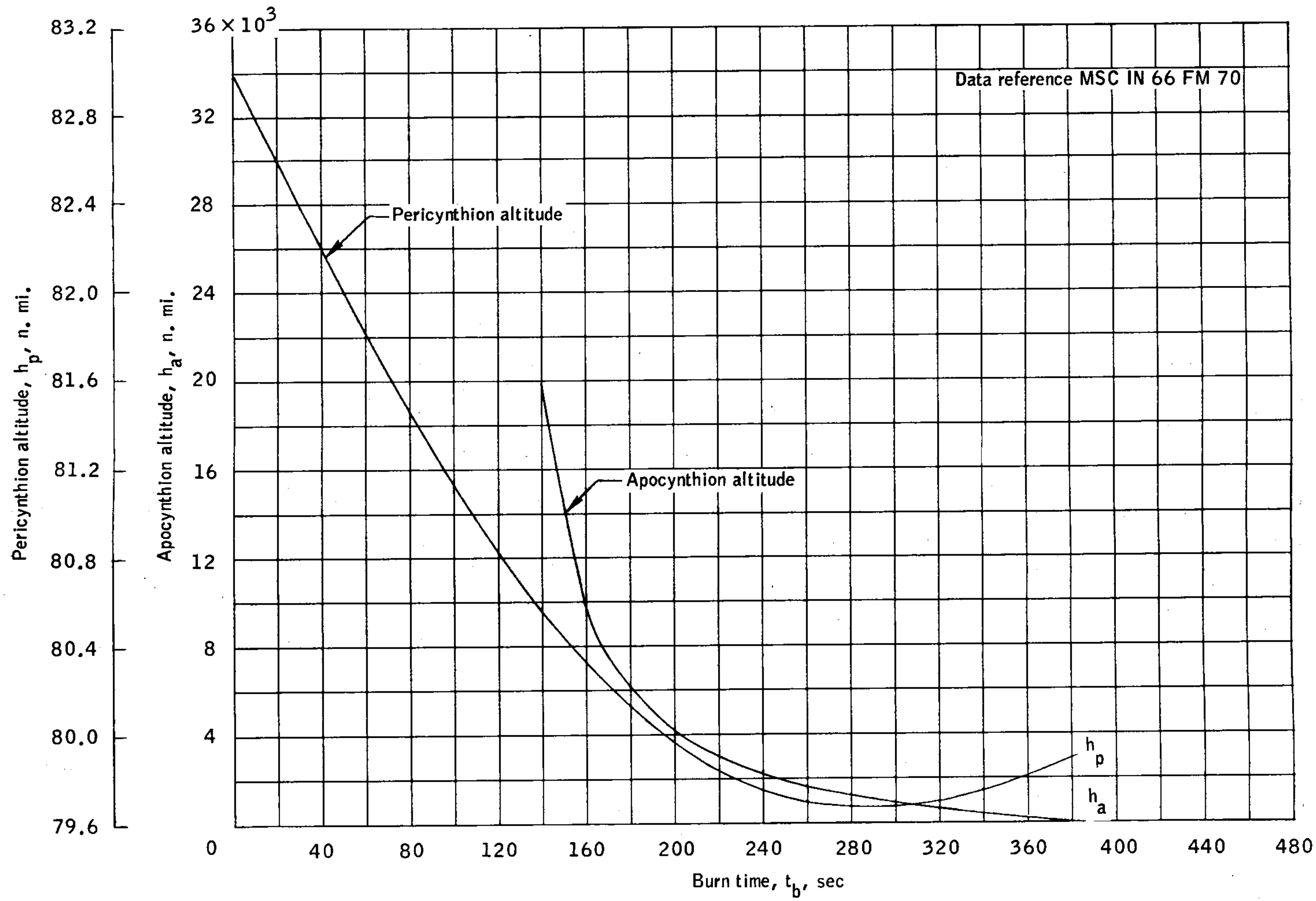
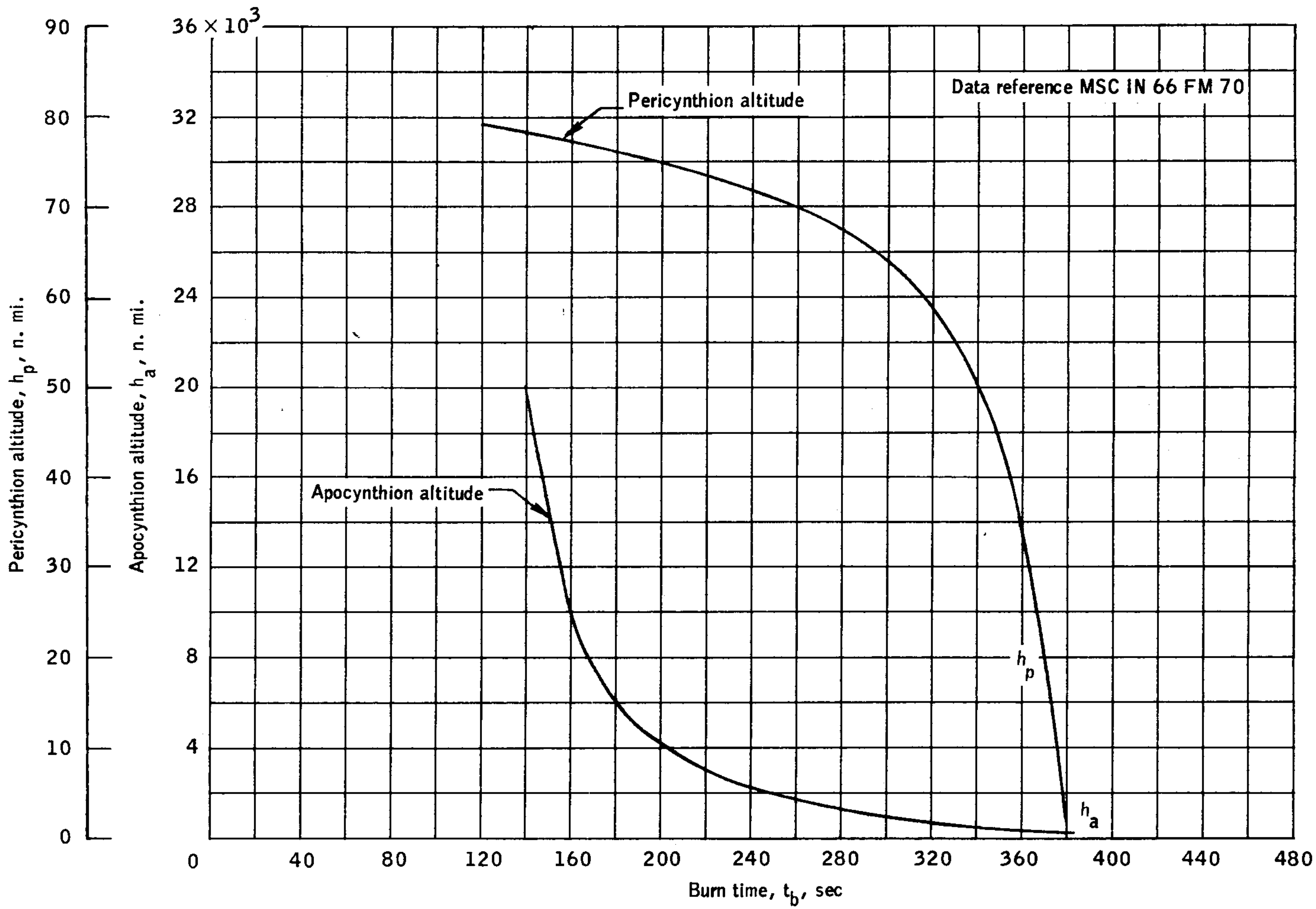


Figure 10.- DSKY parameters through the lunar orbit injection burn.



(a) Nominal burn.

Figure 11.- Pericynthion altitude and apocynthion altitude through the lunar orbit injection burn.



(b) Platform drift of -.05°/sec.

Figure 11.- Concluded.

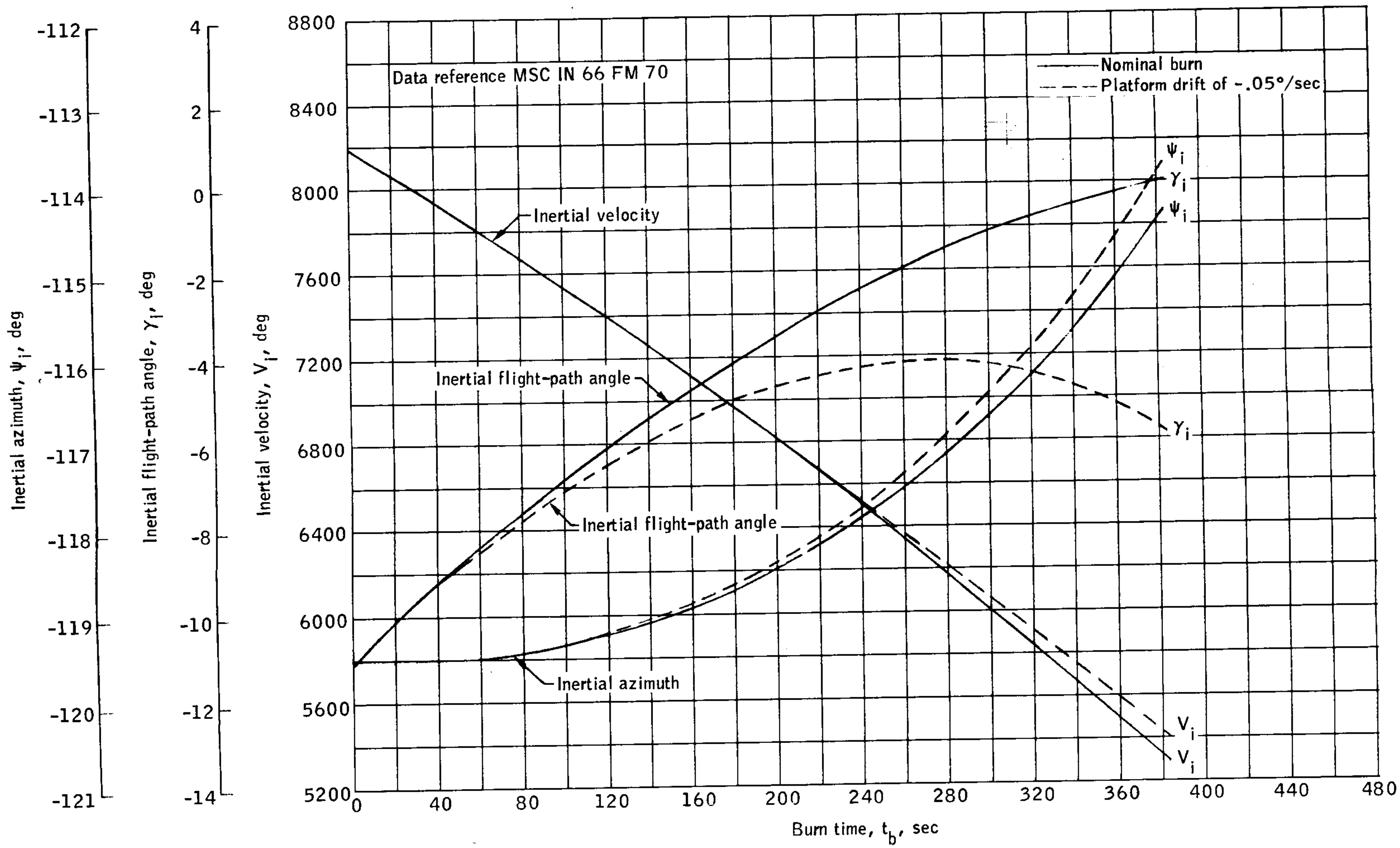


Figure 12.- Inertial velocity, inertial flight-path angle and inertial azimuth with respect to the moon through the lunar orbit injection burn.

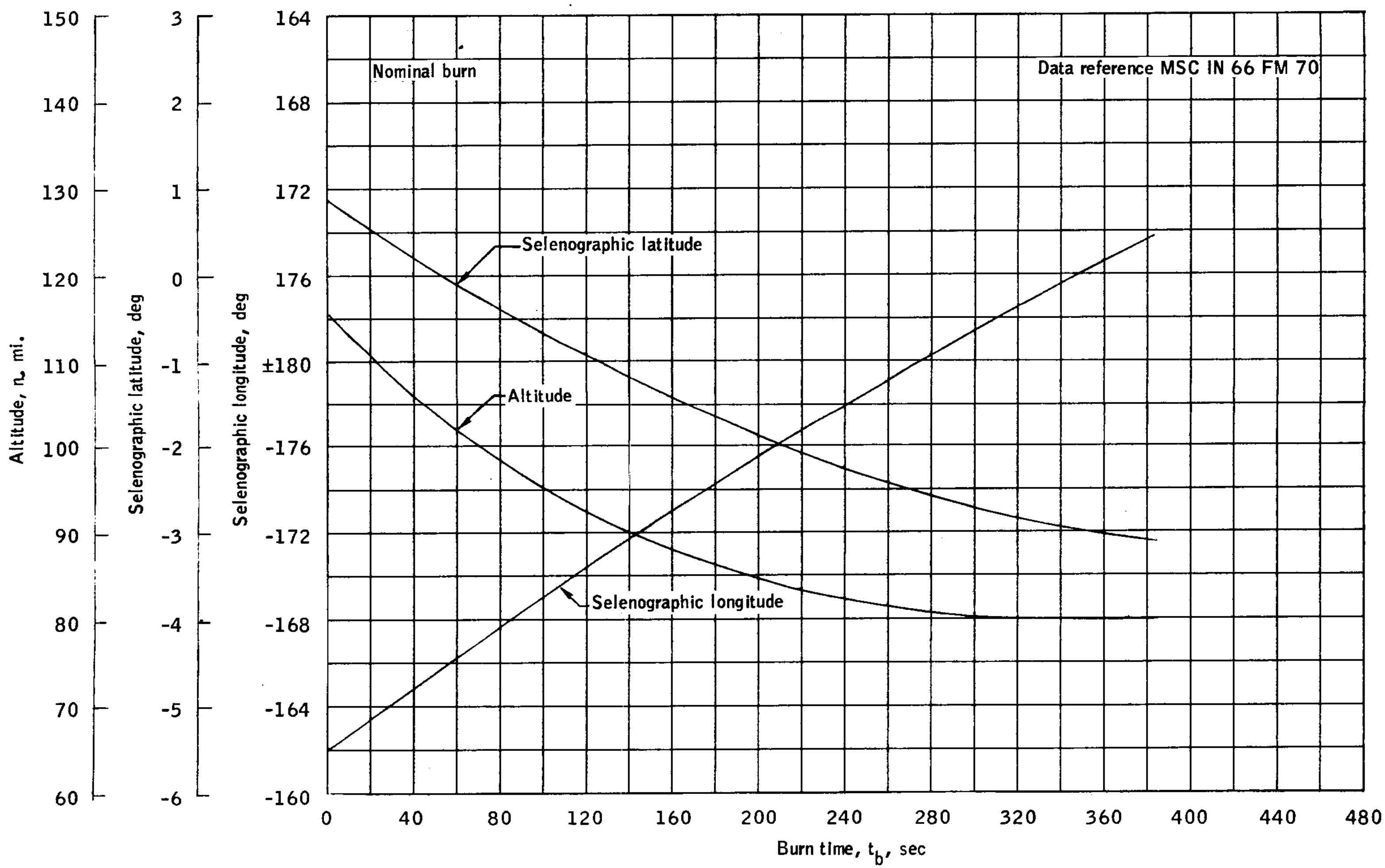


Figure 13.- Selenographic latitude, selenographic longitude, and altitude through the lunar orbit injection burn.

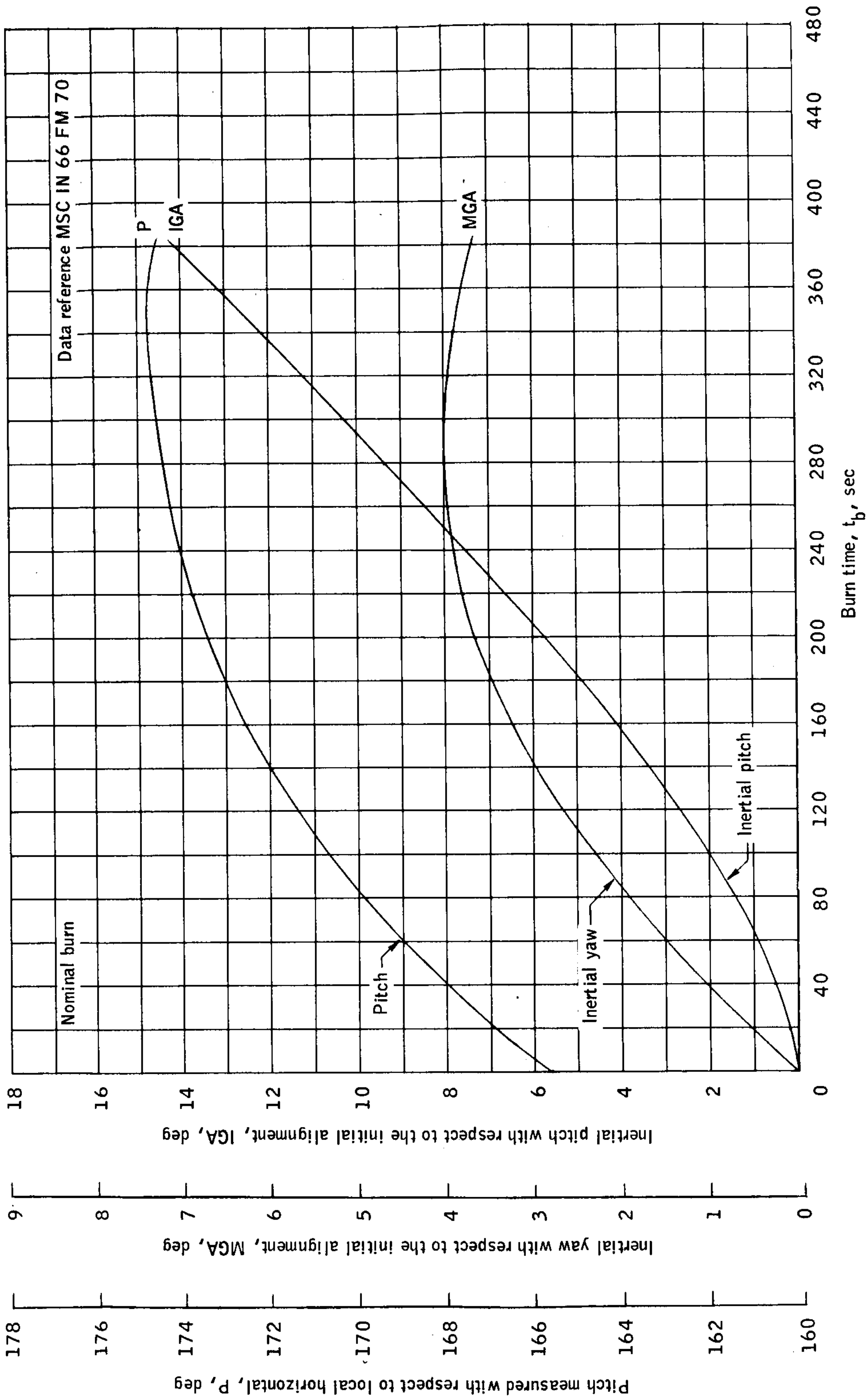


Figure 14.- Spacecraft attitude through the lunar orbit injection burn.

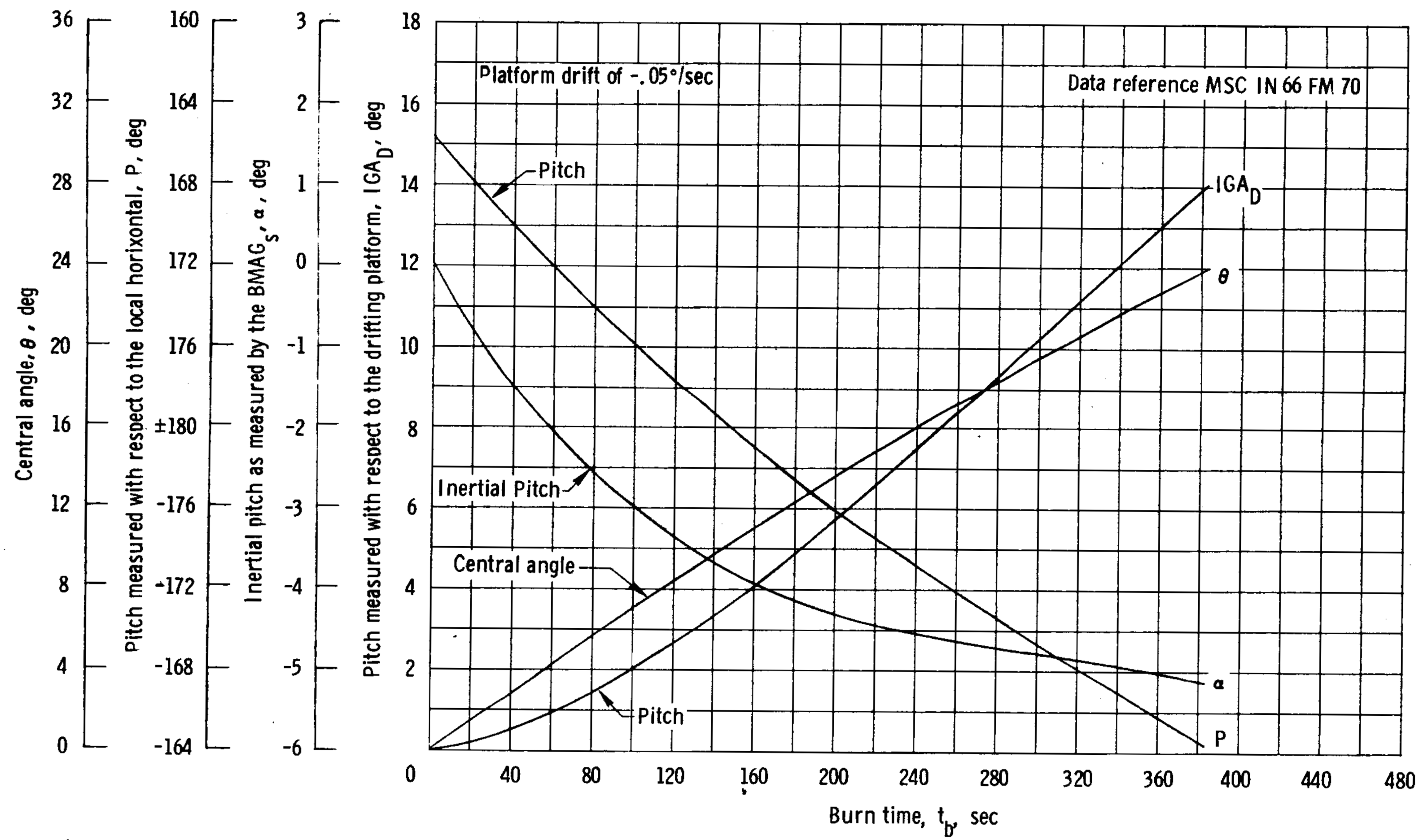
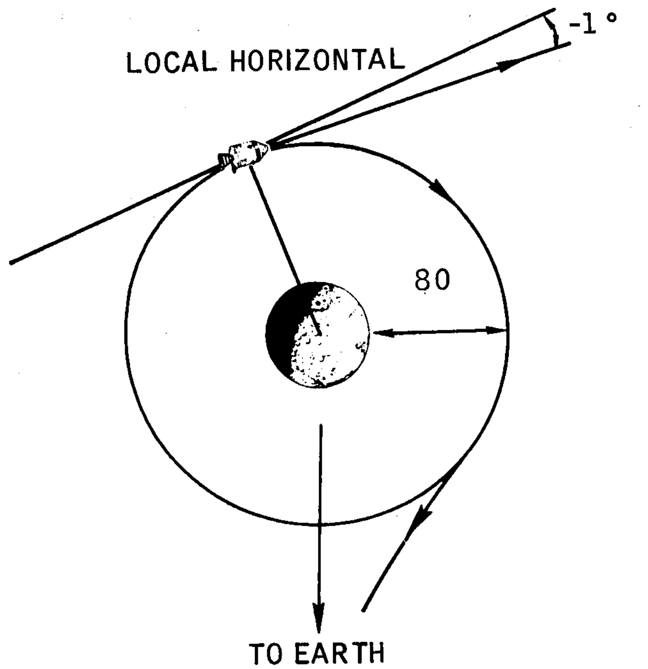
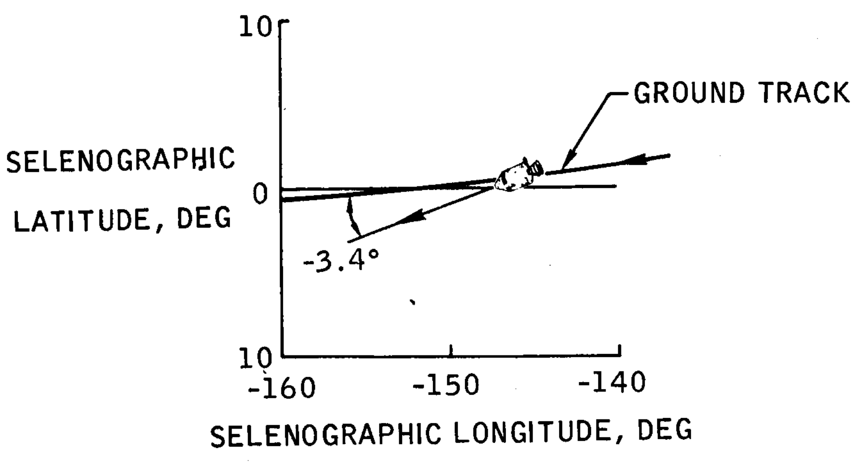


Figure 15. - Spacecraft pitch attitude through the lunar orbit injection burn as performed with a platform drift.



PITCH WITH RESPECT TO LOCAL HORIZONTAL



YAW, LOCAL HORIZONTAL SYSTEM

Figure 16. - Spacecraft attitude at transearth injection.

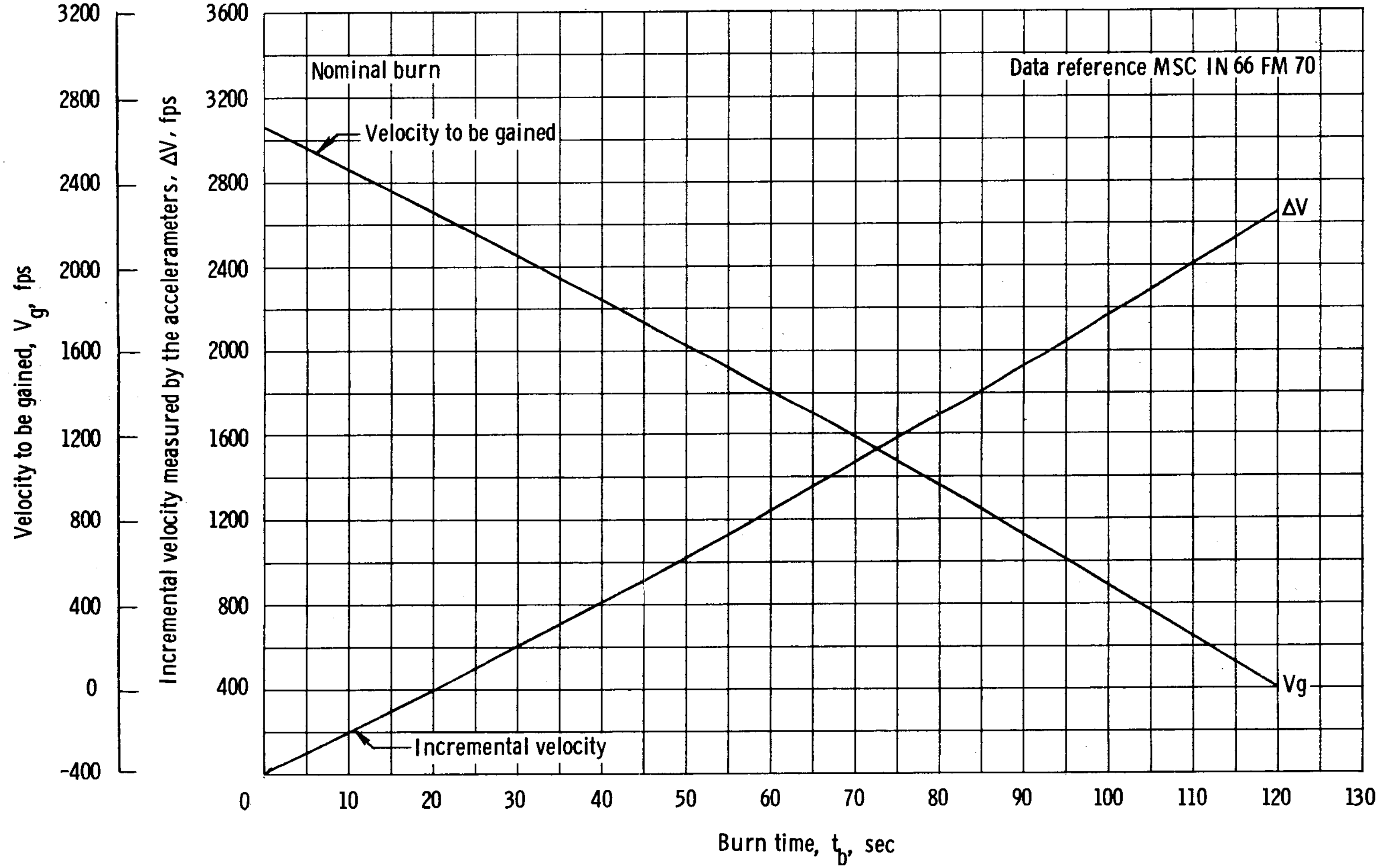


Figure 17. - DSKY parameters through the transearth injection burn.

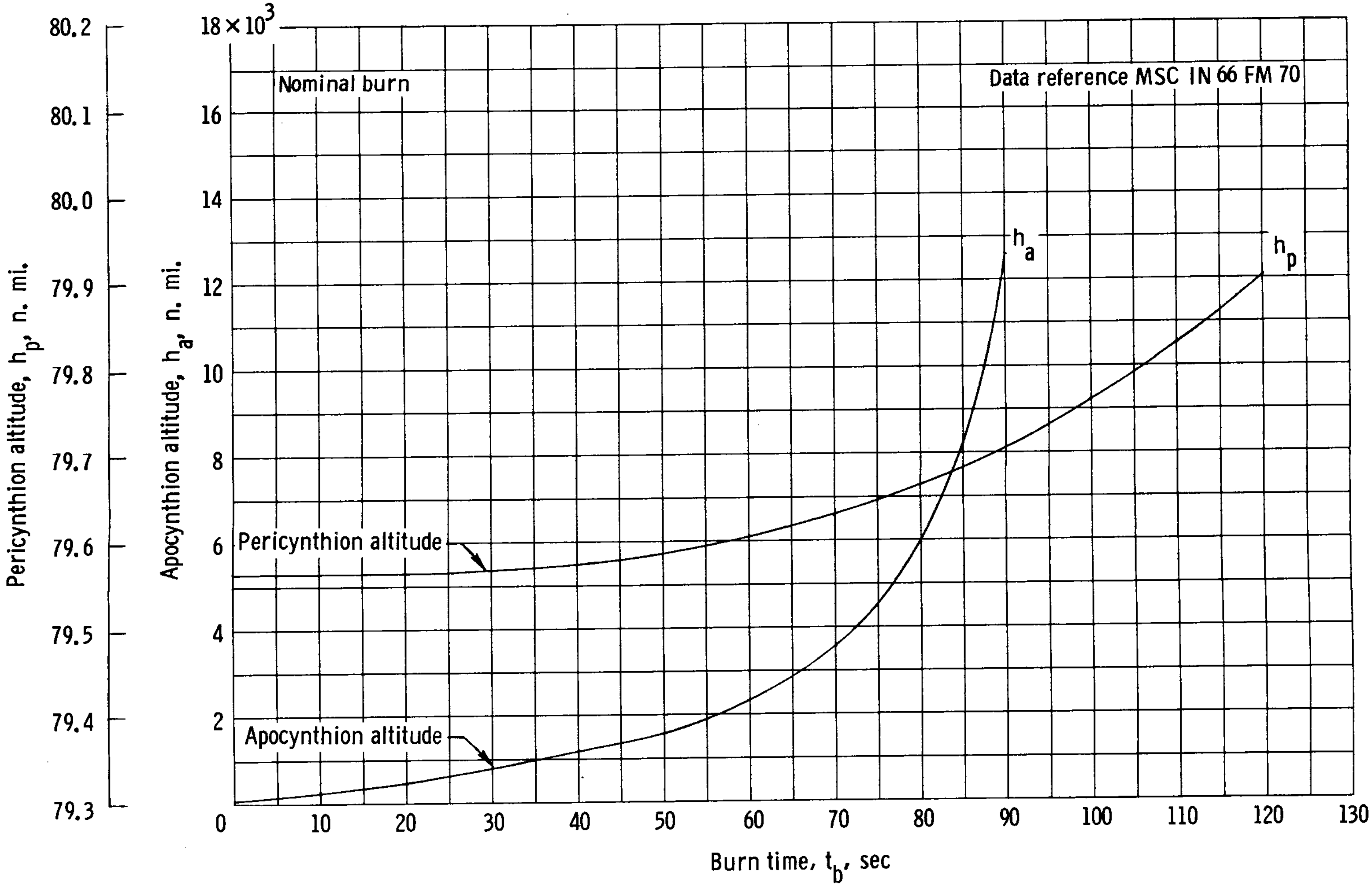


Figure 18. - Pericynthion altitude and apocynthion altitude through the transearth injection burn.

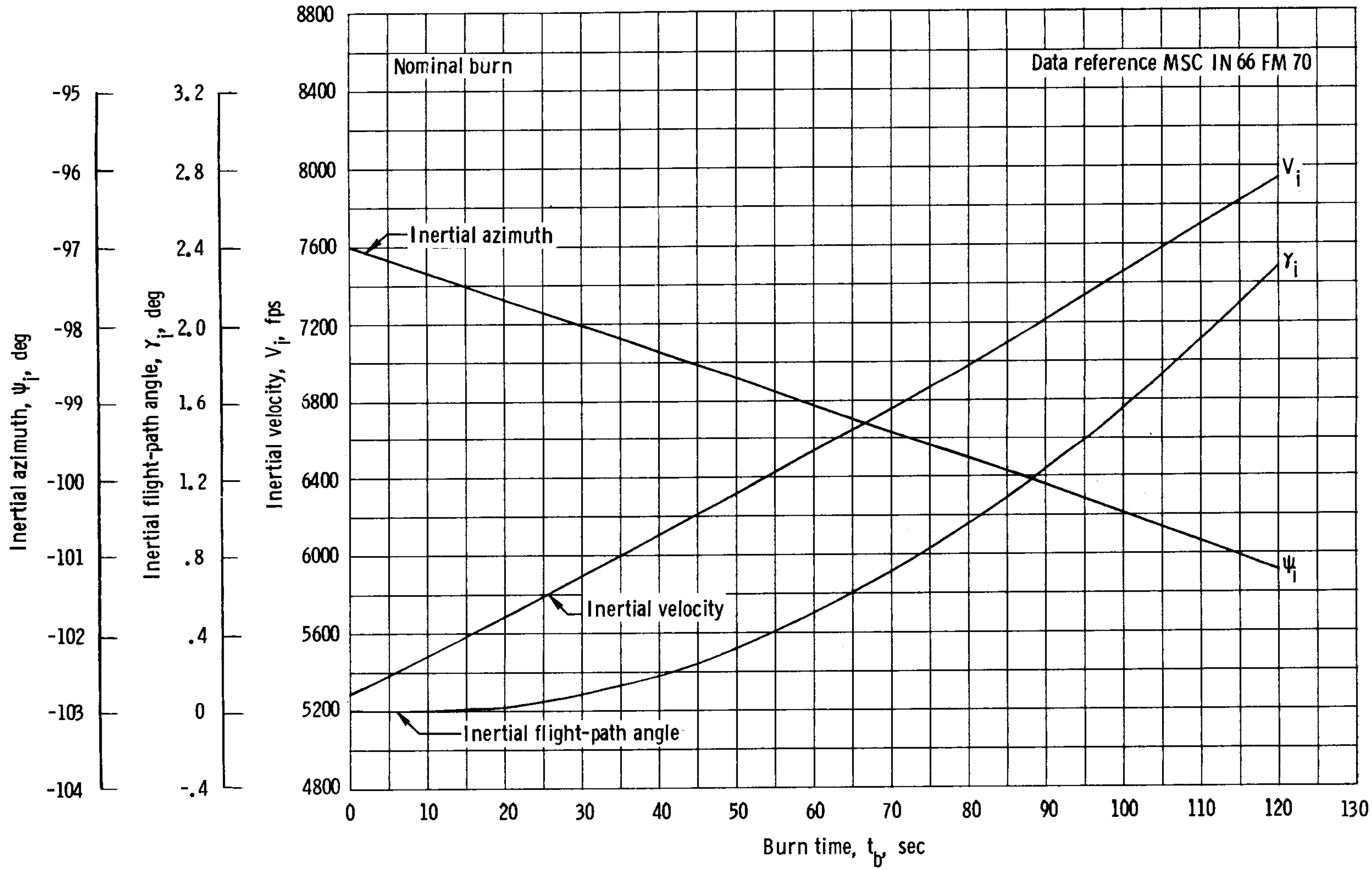


Figure 19.- Inertial velocity, inertial flight-path angle and inertial azimuth with respect to the moon through the transearth injection burn.

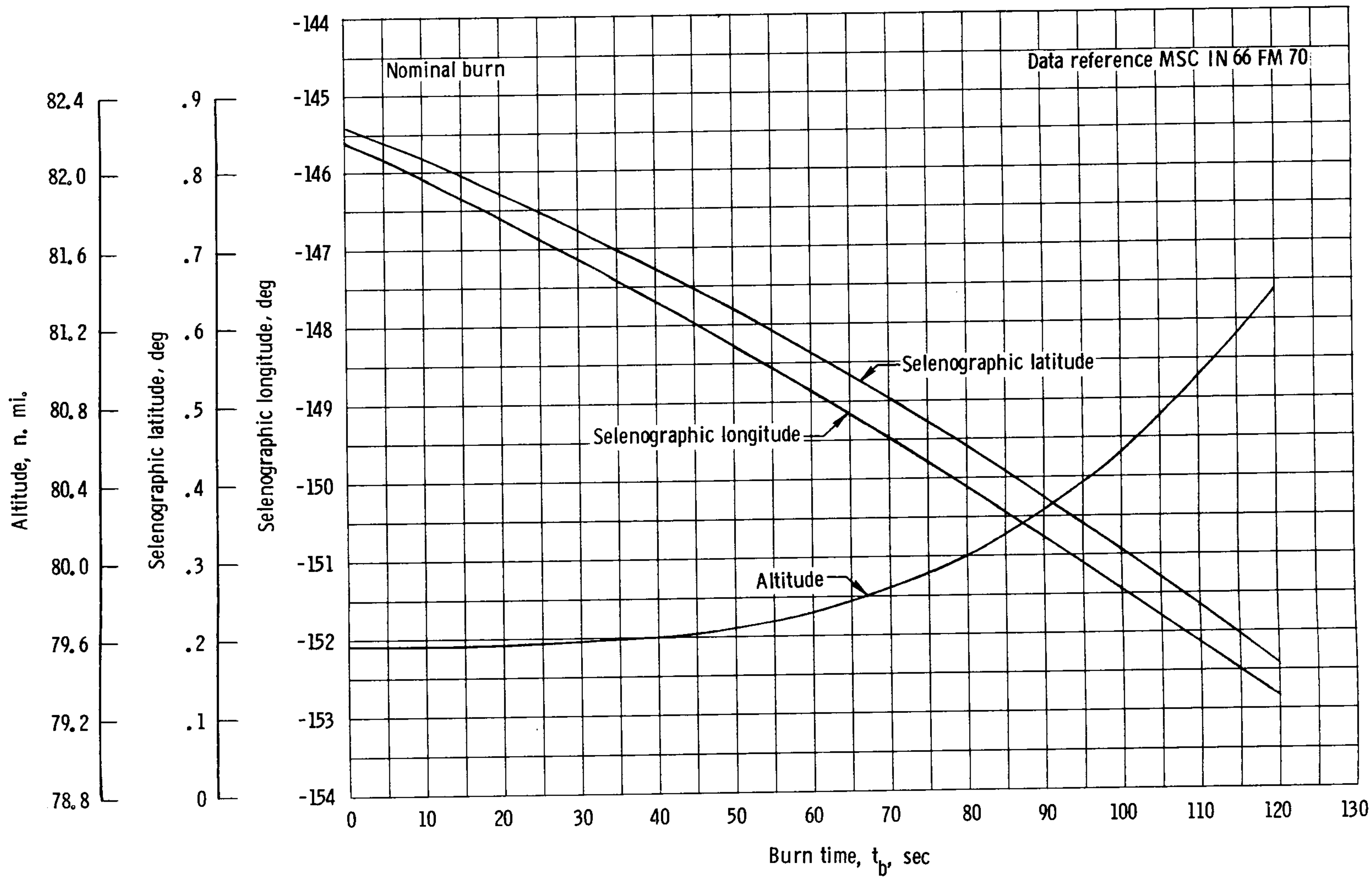


Figure 20. - Selenographic latitude, selenographic longitude and altitude through the transearth injection burn.

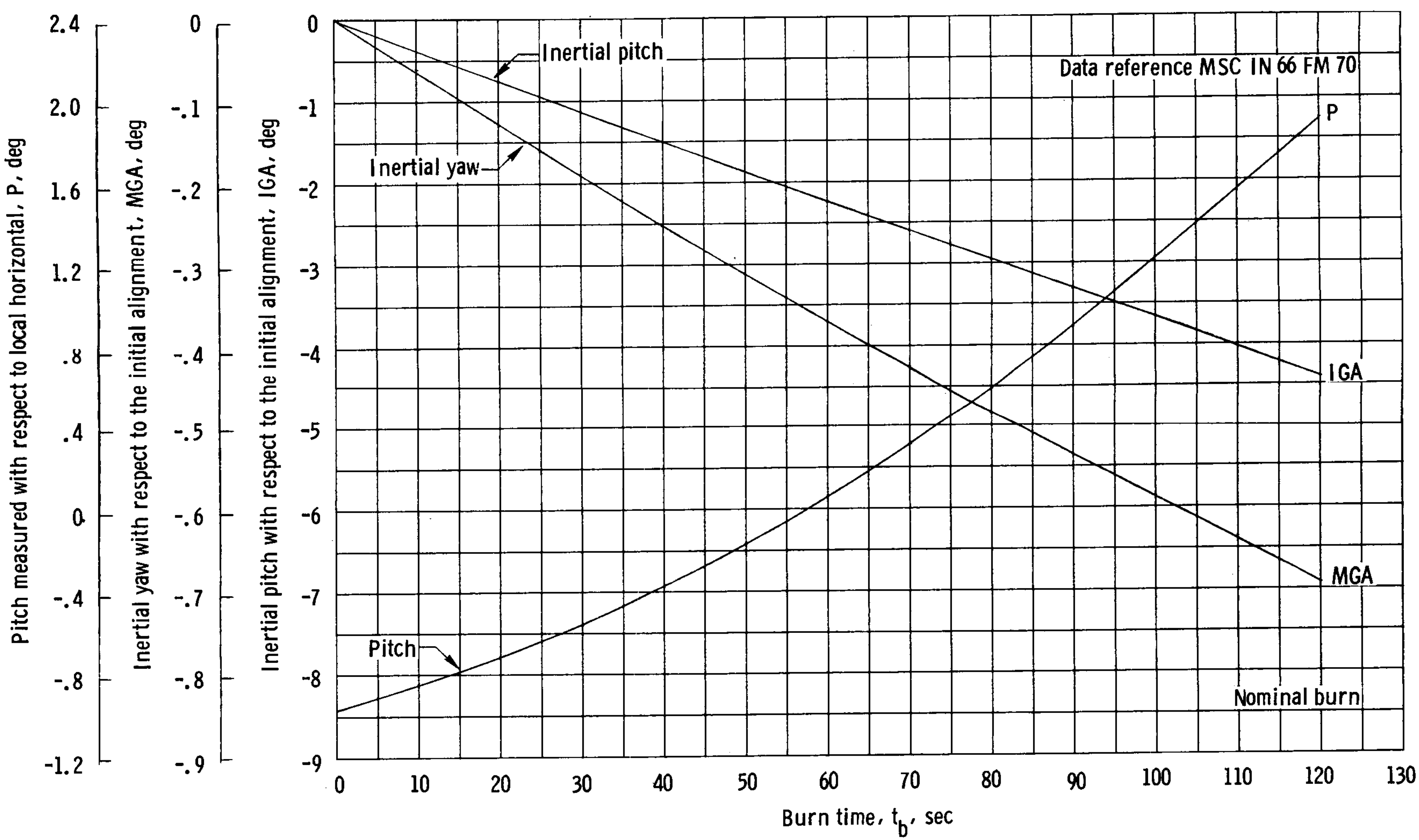


Figure 21. - Spacecraft attitude through the transearth injection burn.

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